Joint Workshop of the TOGA COARE Flux and Oceans Working Groups and the GEWEX Cloud Systems Study Working Group 4

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I. Introduction

The TOGA-COARE Air-Sea Interaction (Flux) Working Group, or sub-sections of it, have held working meetings at various venues on 6 occasions since the end of the COARE IOP in 1993. Reports of the proceedings at each one are available on the COARE Data Information System (CDIS) web site. Initial emphasis at Flux Group workshops was toward improving the accuracy of near-surface meteorological and ocean measurements, in order to obtain more reliable values of surface fluxes in the Pacific warm pool region computed using the bulk method. To the same end, the Group worked on development of improved algorithms and formulae to describe air-sea exchange processes. Much of the progress was based on careful intercomparison and intercalibration of the sensors and techniques used on the various platforms during the experiment. Subsequent workshops dealt with the development of products, maps and algorithms to be made available to the COARE community, in support of scientific analysis and modelling efforts. Two of the workshops, at Boulder in 1995 and Woods Hole in 1996 (Bradley and Weller; 1995a, 1997) were particularly aimed at merging the work of the Flux Group with that of other COARE science groups, those working on large-and medium-scale atmospheric processes, and on mesoscale and global modelling.

To invigorate this interaction, at the Woods Hole meeting it was decided that the next workshop, originally to be joint between the Flux and Ocean groups, would also be amalgamated with a workshop of the GEWEX Cloud Systems Study (GCSS) Working Group 4 - Precipitating Convective Cloud Systems. Thus, the workshop reported here was organized by the Flux Group Co-Chairs, Drs. Frank Bradley and Robert Weller, and the then Chair of GCSS-WG4, Dr. Mitchell Moncrieff, who hosted the meeting at the NCAR Foothills Laboratory in Boulder, Colorado.

It opened with a series of four papers introducing some concepts of meso-scale modeling for the benefit of participants who had little or only superficial understanding of this field. For their part, the Flux Group described progress since the Woods Hole meeting in resolving an important problem that has emerged with the COARE radiosonde humidity observations. A prompt and appropriate solution to this problem is critical to many areas of COARE research. After this session of familiarization with one another's procedures and priorities, the experimental and modeling groups continued their business partly in working groups, partly in plenary. We were mindful that the concept of this meeting foreshadowed the interaction between observational and modeling scientists which is one objective of the COARE review conference planned for July 1998 (COARE98). Many of the participants in this workshop are involved in the planning of COARE98 and a session was therefore devoted to a discussion of this meeting which will transition the COARE results, datasets and experience to related ongoing programs, CLIVAR and GEWEX.

Apart from the soundings problem, other Flux and Ocean data issues arising from the Woods Hole workshop scheduled for discussion and resolution here included rainfall, longwave radiation and correction of aircraft data sets. Production of surface maps of SST, surface currents, rainfall and surface fluxes was also an important area of unfinished business. These maps are needed for modelling effort, but work had been deferred pending work on the basic datasets, and more recently by lack of funding support.

Early in the chronology of these workshops, a 'timeline' was developed setting out a schedule to accomplish the goals of quality control, delivery of flux data sets and other products, and integration of Flux Group science with that of the broader community. This timeline was updated at the COARE data workshop in Toulouse in 1994 (Chinman et al., 1995), as new information became available, and again at the 1996 Woods Hole workshop. Being the final Flux Group workshop, it was deemed necessary to update the timeline as a review of past progress, and to set goals for work leading up to COARE98 and beyond.

We are grateful for the organizational support for this workshop offered by the TCIPO through Director Richard Chinman and Jeanette Walters. Thanks are also due to Jim Pasquotto for support at NCAR during the meeting and help with production of this report.

II. Summary and Timeline

The TOGA-COARE Flux and Oceans working groups met in Boulder in May 1997, jointly with the GEWEX Cloud Systems Study Working Group 4. WG4 scientists are active in the development of cloud-resolving models (CRMs) which hold the promise of providing COARE researchers with high-resolution surface meteorological and flux fields. At the same time, cloud-resolving modellers can benefit from the detailed observations obtained during COARE as they develop parameterizations appropriate to the scale of their models and work toward increasingly realistic simulations of clouds and small and mesoscale convective systems. The meeting provided further impetus for collaborative research on COARE case studies, and for coupling high-resolution atmospheric and oceanic models.

The need to correct the radiosonde soundings made during COARE was a major topic of discussion, together with the various scientific study areas which rely on the soundings data and the effects of the errors. he evidence suggests that in the atmospheric mixed layer, the COARE soundings are biased, being too dry by about 1 g kg^{-1} and showing excessive scatter. This can have serious implications for investigations of atmospheric processes, particularly moisture budgets, or modelling the evolution of clouds. One very serious consequence of this uncertainty is to delay the high resolution COARE reanalysis project planned by ECMWF. However, objective correction schemes have been developed by NCAR ATD, and a schedule for application of these schemes proposed.

Participants from the GCSS working group reported on two case studies using COARE data sets. Case 1 is a detailed study of a squall line cloud system, observed during the mature and decaying phases of its life cycle by airborne Doppler radar. Two- and three-dimensional simulations were performed with 7 different CRMs and 3 single column models (SCMs). Convective processes, surface rainfall, momentum transport and the thermodynamic impacts of the squall line were examined, and realistic simulations of many features reported. Notable differences between 2-D and 3-D modelling of momentum transport were apparent, and 3-D models were found to reproduce the double-peaked updraft structure observed by the 3-D radar. Indications from various aspects of the simulations pointed to the importance of providing good ice phase parameterization.

Whereas the Case 1 event lasted a few hours, Case 2 tested simulation of a 6-day period which included several episodes of deep convection. Model initiation was with IFA-averaged quantities, and the objective was to test the ability of CRMs to reproduce the large-scale time and space-averaged statistics of the convective precipitating cloud systems. 2- and 3-dimensional CRMs, a 3-dimensional mesoscale model, and 5 SCMs were intercompared. Outputs available for comparison with observation include time-series of large-scale temperature and water vapor profiles, and surface turbulent and radiative fluxes. The model output includes some quantities for which observations are inadequate or not available. Some differences between the simulations and COARE observations may result from errors in the imposed large-scale forcing. Whereas Case 1 relies primarily on aircraft observations, Case 2 is more dependent on the IFA observational array and is therefore susceptible to the rawinsonde humidity problem. dditional COARE measurements, such as SSM/I observations, ship radar and wind profiler statistics, all-sky cloud photographs, will be sought to evaluate CRMs further and improve parameterizations.

GCSS WG4 will continue their model intercomparison studies of TOGA COARE cloud systems. n particular, further studies of cloud systems in the December 1992 westerly wind burst will be conducted. he results will be reported at a WG4 meeting in mid-1998. G4 will then simulate a multi-day case in a non-wind-burst environment, for example, containing the aforementioned Jan 7-10 period. he involvement of both cloud-resolving and single-column modellers in WG4 will facilitate the development of physically based convective parameterization schemes for global models and, thereby, the transition of COARE results to CLIVAR-GOALS

Mapping of surface variables continues to focus on products at two different scales, a climatological grid (1°, 4 times a day) and higher resolution (1 km, 10 minute) for certain times in the IFA. rogress was reported on the development of sea surface temperature maps on the climatological grid, and on smaller scales in the center of the IFA. IFA-specific surface current maps are being developed, and also Pacific basin scale at 1° resolution. The NASA TRMM rainfall maps from the merged radar data continue to be available on a 2km x 2km pixel grid every 10 minutes. Further evidence was presented which indicates that discrepancies between rainfall estimates are due to spatial and temporal variability. Analysis by CSU scientists indicates that the radars were situated in a relatively dry region of the IFA, and that the period for which the radar ships were in place was a relatively dry period of the IOP.

Regarding flux mapping, data have been used on days of multiple aircraft missions to provide a “snapshot” of spatial fluxes at high resolution. Efforts for more comprehensive and systematic mapping of the fluxes in the IFA are underway, but have not progressed far. Having devoted so much effort to bring the basic in-situ data sets to the high quality needed to meet the COARE goal for flux accuracy, it is disappointing that the final step of producing gridded fluxes has not been recognized as a high priority in funding decisions, nor attracted a collaborative effort involving remote sensing, modelling and data assimilation investigators, along with those that collected the in-situ data.

In preparation for this workshop, an effort was made to finalize the aircraft data sets, which required examination and agreement on offsets. The UC Irvine group coordinated this and has posted results to the web. With this work completed, the aircraft data are available for archiving with other COARE flux data sets.

To facilitate use of the COARE bulk flux algorithm (version 2.5b), a package has been assembled and made available at several sites on the web. It comprises the FORTRAN source code, a 4-day time series of actual COARE data with which the code may be run, and the correct output for validation. his report also includes a list of publications of work, which has made use of the COARE algorithm, compiled by Chris Fairall; it is apparent that the COARE algorithm has received broad community acceptance.

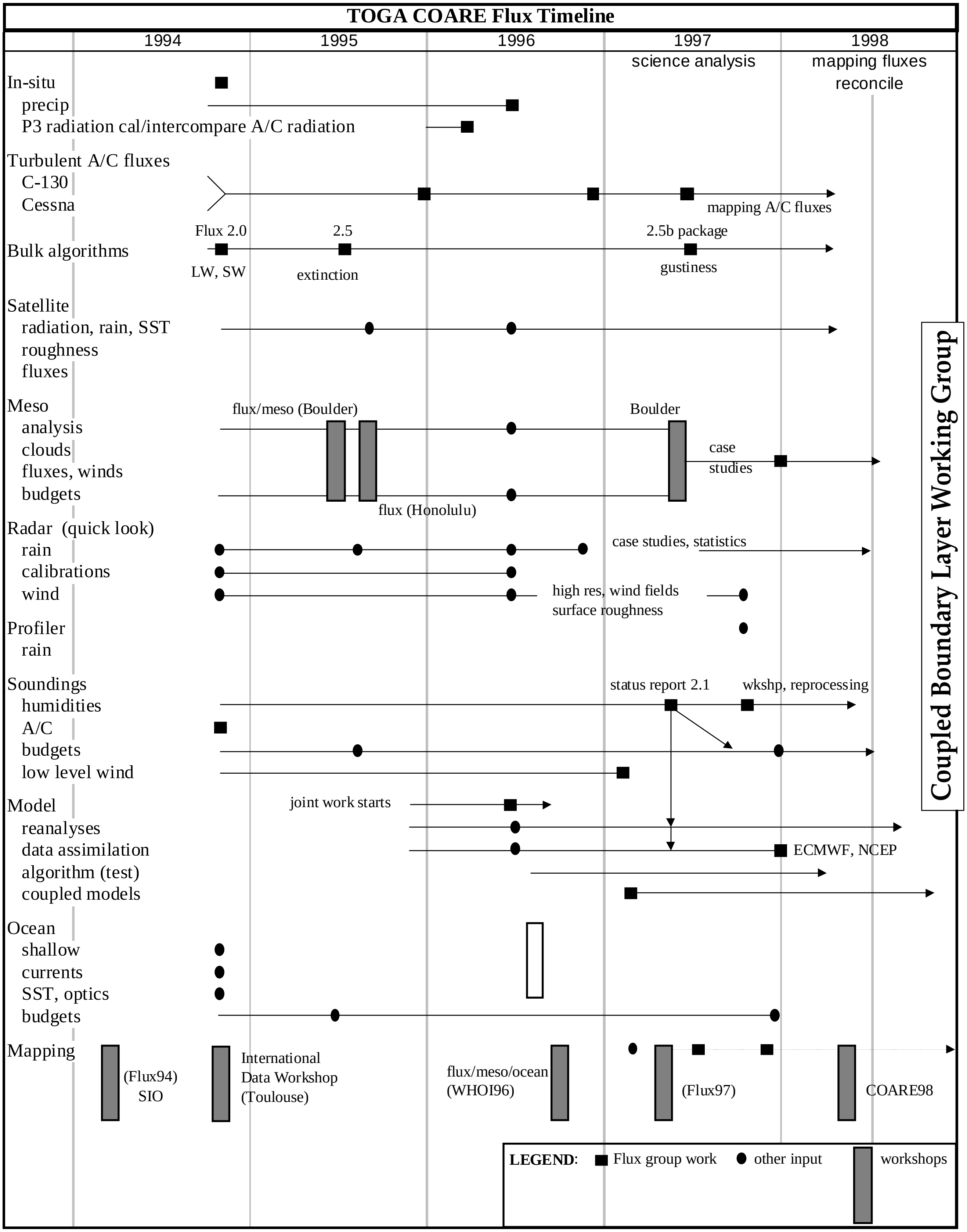
The meeting was informed of the new arrangements for archiving COARE data at NCDC and NODC, and of improved access to the datasets via a revised data catalogue, the TOGA-COARE Data Information System. However, concern remains about how best to notify users about updates and corrections to datasets; the imminent corrections to the soundings for example.

Reports on progress with several ocean models were presented. The meeting was not intended to focus on ocean modelling, but these reports were included to indicate similarities in the progress and needs of this work. Ocean modellers, like atmospheric modellers, have been using COARE data to push toward higher resolution 3-D ocean models. Anderson, for example, discussed an ocean model forced by surface fluxes from a CRM. Interest was evident in working toward coupled high resolution models, using COARE data from the IFA for motivation and validation. Ocean modellers also expressed the need for COARE flux maps on the climatological as well as the high-resolution grid.

The TOGA-COARE Flux Group timeline was discussed and updated (Figure1), and provides an overview of both past work by the Flux Group and future directions. We note that many of the milestones we set for this group's activities have been achieved. Difficulties with the quality of the radiosonde data provide a final challenge and a reminder of the effort, care and support required to make good measurements. Overall, the COARE Flux Group's work in the field and, subsequently, in reconciling diverse measurement methods and in developing a bulk flux algorithm for community use, has been an outstanding success. The final mapping of flux fields has not yet gained the momentum we had hoped would develop, but when reanalysis and satellite surface flux fields become available, the critical need for surface flux fields in so many areas of climate research will surely help to motivate this work.

This will be the last report from a COARE Flux Group workshop. Continuing responsibility in this area will be pursued by the Coupled Boundary Layer Working Group (CBLWG), which is being constituted under CLIVAR. An important legacy of the Flux Group has been its success in cutting across the disciplines and scales of COARE atmospheric and ocean science, and in bringing together modellers and observers. A goal of the CBLWG will be to see that this continues, and a session of this workshop was devoted to discussing interfaces and links between field programs and modelling efforts. Links between the Flux Group's work and achievements, and future CLIVAR-GOALS programs were discussed, including the Pan-American Climate Study (PACS), and proposed work in the Bay of Bengal (Joint Air-Sea Monsoon Experiment, JASMINE). The transition from COARE to CLIVAR is a major *raison d'être* for the COARE98 conference/workshop planned for July 1998 in Boulder. It will aim to foster future interaction between observers and modellers. A final session of this workshop was devoted to discussions of the scientific content of COARE98.

FIGURE 1


TOGA COARE Flux Timeline
1994
1995
1996
1997
1998
science analysis
mapping fluxes
reconcile
In-situ
precip
P3 radiation cal/intercompare A/C radiation
Turbulent A/C fluxes
C-130
Cessna
mapping A/C fluxes
Flux 2.0
2.5
2.5b package
Bulk algorithms
LW, SW
extinction
gustiness
Satellite
radiation, rain, SST
roughness
fluxes
Meso
analysis
clouds
fluxes, winds
budgets
flux/meso (Boulder)
Boulder
case
studies
flux (Honolulu)
Radar (quick look)
rain
calibrations
wind
case studies, statistics
high res, wind fields
surface roughness
Profiler
rain
Soundings
humidities
A/C
budgets
low level wind
status report 2.1
wkshp, reprocessing
Model
reanalyses
data assimilation
algorithm (test)
coupled models
joint work starts
ECMWF, NCEP
Ocean
shallow
currents
SST, optics
budgets
Mapping
(Flux94)
SIO
International
Data Workshop
(Toulouse)
flux/meso/ocean
(WHOI96)
(Flux97)
COARE98
LEGEND:
Flux group work
other input
workshops
Coupled Boundary Layer Working Group

III. Workshop Agenda

Wed 14 May 1997

0800 Coffee

0825 Welcome

0830 Mesoscale modeling strategies

	Wu	20 mins
	Tao	20 mins
	Redelsperger	20 mins
	Zhang	20 mins
0950	Discussion	40 mins

1030 Break

1100 Soundings reports

	Zipser	20 mins
	Johnson/Parsons	20 mins
	Holland/Fairall	20 mins
1220	Discussion	40 mins

1300 Lunch

1400 Brief account of model intercomparison results, in plenary

Kreuger - GCSS Case 1, 19-26 Dec 1992 20 mins

Redelsperger - GCSS Case 2, 22 Feb 1993 20 mins

1440 Working groups in parallel - Soundings, WG4

1530 Coffee on the run

1730 Close

Thurs 15 May 1997

0800 Coffee

0830 Reports from Breakouts and Discussion

WG4 60 mins

Soundings 60 mins

1030 Break

1100 Mapping reports

SST and SSS fields - Paulson

Current Fields - Hacker

Radiation and Clouds - Johnson/Rossow

Rainfall maps - Short

Mapping Working Group Discussion

(Anderson, Weller, Rogers, Curry, Fairall, Khelif, Lagerloef, Paulson, Short, Zhang, Zhao)

1300 Lunch

1400 Flux/Oceans Data reports

Aircraft correction set - Khelif 15 mins

Turbulence flux data sets - Bradley, Fairall 15 mins

Bulk algorithm and test data - Fairall, Bradley 15 mins

Data archiving - Chinman, JOSS rep. 15mins

1500 Progress with ocean models

(Anderson, Weller, Redelsperger, Richardson)

1530 Break

1600 Plenary Discussion

Significance of mapping for WG4, Flux, Oceans
Discussion of coupling mechanisms
Strategy and timetable for product delivery
Other issues arising from day's proceedings

1730 Close

Fri 16 May 1997

0800 Coffee

Reviews/Discussion to identify "gaps" hindering model development, to plan strategies to further COARE science and its synthesis, and for the transition to CLIVAR

0830 Lukas -formation of a Coupled Boundary-Layer Working Group (CBLWG)

0845 Views on the need and goals for such a group
(Anderson, Bradley, Chen, Hacker, Johnson, Khelif, Kreuger, Lagerloef, Paulson, Plueddemann, Richardson, Weller)

0915 Webster - The status of CLIVAR-GOALS: possible benefits from COARE.

0930 Potential for COARE science and field experience to contribute to future programs.

Johnson - South China Sea Experiment
Anderson - PACS
Webster - Austral Asian experiment

0945 Moncrieff - COARE-related work underway within GCSS/GEWEX: links and data needs.

1000 Sperber - A NEG-1 perspective on COARE as a resource

1015 The interfaces between COARE science/analysis and operational modeling
Rogers - status of the interface to operational groups
Bradley - Joint JSC/SCOR working group on air-sea fluxes

1030 Break

1100 Panel Discussion (Weller, Lukas, Moncrieff, Hacker, Bradley, Webster, Sperber)
Synthesize issues of continuing COARE science and applications
Develop strategy, roadmap, timeline for a CBLWG

1200 Bradley/Lukas - Role of COARE98 in this strategy

1300 Lunch

1400 COARE98 Planning Session

Topics, format, schedule
Working groups and timelines to prepare for COARE98
Collaborations Flux/WG4/Oceans/NEG-1
Reanalysis (ECMWF/NCEP)

1530 Break

1600 Wind-up

Review and agree on:

Recommendations from group
Action items
Writing assignments
Reports
Time-line
Meetings beyond COARE98

1700 Close

IV. Mesoscale Modeling Strategies

Modeling of TOGA COARE Cloud Systems and Environmental Effects

Three presentations (Tao, Redelsperger, and Wu) concerned various aspects of mesoscale modeling but with a slant toward the large-scale role of precipitating convective cloud systems studied using cloud-resolving models (CRMs). Two types of CRM are used. The first is essentially the classical cloud model, used mainly to examine convective processes in detail on time scales of hours. The second addresses the long-term effects of cloud systems, with special attention to their large-scale effects, in particular, to parameterization in general circulation models (See section VI herein for more discussion on CRMs and their applications). The fourth presentation (Zhang) focused on a dynamically based way to assimilate/analyze data from a distributed array of soundings and other observations.

W. K. Tao (NASA Goddard Space Flight Center) showed results from CRM studies demonstrating that ocean surface fluxes and cloud-longwave radiative interactive processes can enhance precipitation, but cloud-solar radiative processes can reduce convective activity. However, the magnitude of the impact of ocean surface fluxes, radiation and microphysics on convective - precipitation processes is quite different in these two types of modeled convection. It was found that there was less of an impact by radiative processes and surface processes on the first type of CRM described above than on the second type. This is because the two dominant terms in the water and temperature budgets are net condensation and imposed large-scale advective cooling and moistening in the continuous large-scale forced convection. The net condensation is mainly a response of imposed large-scale forcing. These results are consistent with previous works (see review by Tao et al., 1996). Analysis of the moisture budget shows that large-scale convergence often corresponds to precipitation, but there are occasions when precipitation corresponds to a large reduction of column precipitable and column-moisture divergence. Analysis of the momentum budget shows the large magnitude of the sub-grid momentum sources and sinks (about $4ms^{-1}$ per hour) in the convective events.

J.-L. Redelsperger (Meteo-France) presented CRM studies of two deep convective cases observed during COARE (26 Nov ‘92 and 17 Feb ‘93) simulated in a 3-D framework by Jabouille et al (1996). Most of surface process schemes in GCMs use formulae based on local variables, and assume horizontal homogeneity at the gridscale. However, this assumption is not valid when boundary layer convective activity or deep convection occurs. Mesoscale variability is hard to determine with present local measurements. Numerical simulations enable one to span time-space scales corresponding to variability induced by convective activity. Numerical results were compared to observed surface parameters and fluxes. Downdrafts produced by convective clouds bring colder air in contact with sea surface and locally increase the windspeed. An enhancement of two times for the latent heat flux and more than three times for the sensible heat flux are found in the rainy area. Intense wind gusts generated by the convective outflow are responsible for this increase. The numerical simulations allow us to estimate the variability of surface fluxes from the grid scale of the cloud model (approx 1km) up to the scale corresponding to a GCM grid box (approx 100km). In a GCM, the key issue is to determine the effective value of fluxes from the knowledge of gridded variables. In regard to previous remarks, special attention must be given to the determination of the mean wind speed. Due to subgrid variability, the mean wind vector (predicted by GCM) does not take into account all changes in the wind speed induced by convection and underestimates it. Based both on time series from numerical results and observations, it is proposed to increase the magnitude of the mean wind vector by adding U_G, a gustiness generated by precipitating deep convection. A simple relationship between U_G and the precipitation rate was found using characteristics of density currents in the western tropical Pacific.

A one-week 2-D simulation recently performed by Zulauf and Krueger (1997) for an idealized case corresponding to GATE environmental conditions gave similar results to Jabouille et al (1996). Preliminary results indicate that the gustiness velocity can also be related to the updraft and downdraft mass fluxes, in which case it may be possible to link gustiness to the convective parameterization.

One shallow convection case (28 Nov 92; day of flux intercomparison) was simulated by Mondon and Redelsperger (1997). The model has a fine grid (50m x 50m x 50m). After a validation of results with aircraft measurements in the PBL, LES is used to estimate the free convection gustiness parameter β from the equation

$$\beta = \left(\overline{U}^2 - \overline{\vec{U}}^2\right)^{\frac{1}{2}} w_*$$

where $\overline{U}$ is the mean wind speed and $\overline{\vec{U}}$ the mean wind vector. The "true" value of β was compared to estimates from time variance β_t (as deduced from local observations) and spatial variance β_s (as deduced from aircraft observations). LES simulations lead to a value of $\beta = 0.6$. Observed and simulated β_t and β_s show $\beta_s = \beta_s = 0.8$. Theoretical work (Jabouille et al 1996) indicates that $\alpha = \beta / \beta_s = 0.8$, close to the present value of $\alpha = 0.75$. A general formulation of effective wind for surface fluxes was proposed, that distinguishes the effect of free convection in boundary layer and precipitating deep convection:

$$\overline{U}^2 = \left(\overline{\vec{U}}\right) + \left(\beta w_*\right)^2 + U_G{}^2$$

where β is an empirical factor equal to 0.6, $\left(w_*\right)^3 = -gZ_i T_v \overline{w' T_v'}$ (free convection velocity).

Xiaoqing Wu (in collaboration with Moncrieff and Grabowski, NCAR) presented recent results of a 39-day (Dec.5, 1992-Jan.12, 1993) CRM simulation of TOGA COARE cloud systems. One of the key aspects was that the large-scale forcing was specified from TOGA COARE observations. The CRM produced cloud-scale fields consistent with this forcing. Such fine-scale properties are impossible to observe directly (e.g., updraft and downdraft mass fluxes). Although model evaluation continues, cloud-radiation and cloud-ocean interactions have been substantially quantified. For example, the mesoscale enhancement of surface fluxes was examined using model-generated 39-day cloud-scale (3km spatial resolution and 15min temporal resolution) variables. The results support the finding by Esbensen and McPhaden (1996) and others. The 39-day means of mesoscale enhancement are 20% and 28% for the surface latent and sensible heat fluxes, respectively. The mesoscale enhancement is due to both the weak surface winds and the cloud systems. The magnitude of mesoscale enhancement may be affected by the two-dimensional CRM used and by the spatially uniform sea surface temperature (SST) prescribed. In terms of results from the 7-day simulation of GATE cloud systems, the mesoscale enhancement of surface fluxes is 3% more in the 3-D simulation than the 2-D. Some of the results, for example, the updraft and downdraft mass fluxes, are being used to improve existing mass-flux-based convective parameterization schemes at the ECMWF and the NCAR Community Climate Model version 3 (CCM3) which is the atmospheric component of the NSF/NCAR Climate System Model (CSM).

On-going work includes explicitly coupling the CRM reported in Wu et al. (1997) with an ocean model (in collaboration with Bill Large and Ralph Milliff CGD/NCAR). It was shown that the simple surface energy budget equation for an oceanic mixed layer could not concurrently produce the long-term behavior of the SST and the amplitude of the diurnal cycle. As the first step, dynamically consistent surface forcing from the CRM (validated using the IMET data from Anderson and Weller) was used to force a 1-D ocean model (Large et al. 1994). The preliminary results show that the 1-D ocean model with a nonlocal K profile parameterization can simulate the major feature of the warm pool response to the atmospheric forcing. However, a difference between model-produced and observed SST still exists, most likely due to vertical oceanic mixing because this is one of the key physical processes affecting the SST evolution. Observational studies by several ocean groups show quite significant oceanic transports during the late period of 39-day simulation. Work is underway to include this process into the ocean model and to fully couple the CRM to the ocean model.

M. H. Zhang (SUNY) addressed a key issue in TOGA COARE (and other field experiments in which a distributed array of soundings and other measurements are made) concerning the production of a dynamically and thermodynamically consistent data set from observational data. For the purpose of deriving grid-scale vertical velocity and advective tendencies from sounding measurements, Zhang has derived an objective scheme to process atmospheric soundings of winds, temperature and water vapor mixing ratio over a network of a small number of stations. Given the inevitable uncertainties in the original data, state variables of the atmosphere are adjusted by the smallest possible amount in order to conserve column-integrated mass, moisture, static energy and momentum. The scheme has the capability of incorporating a variety of supplemental measurements to constrain large-scale velocity and advective tendencies derived from state variables.

The method has been implemented to process the Atmospheric Radiation Measurement (ARM) program's soundings of winds, temperature and water vapor mixing ratio at the boundary facilities around the Cloud and Radiation Testbed (CART) site in Northern Oklahoma in April 1994. It is found that state variables are adjusted by an amount comparable to their measurement uncertainties to satisfy the conservation requirements of mass, water vapor, heat, and momentum. Without these adjustments, spurious residual sources and sinks in the column budget of each quantity have the same magnitudes as other leading components. Sensitivities of the diagnosed vertical velocity and apparent heat, moisture and momentum sources, to the number of conservation constraints are presented. It is shown that constraints of column budget of moisture and dry static energy can make large differences to these diagnostics, especially when some original sounding data are missing and have to be interpolated. The method could be used to process TOGA COARE observations.

V. Soundings and Atmospheric Budgets

Ed Zipser reviewed the evidence for the existence of humidity errors in the COARE radiosonde data. He opened the soundings session by acknowledging the group that has been working on the soundings humidity problem from various angles. He pointed out that, while the scatter in humidity observations is large, the bias is larger and of course more serious. Zipser took examples from GATE and ATEX to illustrate that the humidity mixing ratio over the ocean decreased very little, generally less than 1 g kg^{-1} through the depth of the mixed layer, irrespective of atmospheric conditions. From COARE soundings data, the difference Δq between an average mixed layer humidity and the near-surface value was unreasonably large, typically 2-3 g kg^{-1}. But taking low wind speed and clear sky data on the Nov. 28 intercomparison day, a consensus of ship and mooring surface values compared with aircraft data at 40m gave Δq about 0.5 g kg^{-1}. Similar estimates on 13-14 Nov., 2 Dec. and 19 Jan. gave 0.9, 0.7 and 0.9 g kg^{-1} respectively. More evidence of unreliable humidity soundings came from the seemingly unrealistic gradient of CAPE across the IFA from 1876 to 697 Jkg^{-1}. Furthermore, the Weather Service's switch from VIZ to Vaisala sondes at 8 stations across the Pacific could be clearly distinguished in the time series of humidity, supporting Zipser's contention of instrumental bias in the sonde humidity sensors.

Zipser suggested that a reasonable value for Δq was 1.0 to 1.3 g kg^{-1} between "surface" and the 100-400m average. The COARE 2.5 bulk algorithm, based on Monin-Obuhkov similarity theory, supports this predicting Δq ~0.5 g kg^{-1} for light winds and ~1.2 g kg^{-1} for winds greater than 4 ms^{-1}. While the correction needed seems to be site and cruise-specific, a typical value would be about +0.75 g kg^{-1}. Lucas, LeMone and Zipser (LLZ) have devised a correction scheme. Using ship #3 as an example, Zipser illustrated the effect of the LLZ correction in reducing scatter in the observed Δq, relative to the COARE archived data set, over the 4 months of the IOP. Zipser concluded that LLZ is not too bad if an urgent fix is needed, but we should work towards a more physically based, more objective solution to the problem.

Chris Fairall described observations of Δq from three different cruises; COARE (Moana Wave, surface obs. height =15m), the Combined Sensor Program (CSP, Discoverer, 20m) and the Atlantic Stratocumulus Transition Experiment (ASTEX, Baldrige, 18m) near the Azores. Two soundings heights were used, 50 and 100m. For COARE and CSP, both in the western Pacific, the behavior of Δq was almost identical. Taking medians of the frequency distributions for all COARE soundings at 100m, Δq = 2.1 g kg^{-1} and for CSP, 2.0 g kg^{-1}. For nighttime only, the Δq's were 1.9 and 2.0 g kg^{-1} respectively. The average humidity decrease between the sea surface and 15m during COARE was 6.8 g kg^{-1} at air temperature above 27.6°C. During ASTEX the situation was different; the air temperature was about 19.8°C, the decrease in q from the sea surface to 18m height was 4.7 g kg^{-1} with only a further 0.6 g kg^{-1} to 100m (0.5 night only).

All the above frequency distributions have standard deviations between 0.7 and 0.8 g kg^{-1}. Allowing perhaps that the 100 to 400m average is 0.5 g kg^{-1} below the 100m humidity observed by Fairall, his "surface" to mixed layer Δq is about 1.5 g kg^{-1} for the western Pacific COARE and CSP values, at the upper limit of Zipser's suggested "reasonable" value. In response to a query from Roger Lukas, Fairall indicated that, apart from there being no Madden-Julian Oscillation (MJO), the CSP cruise conditions, fluxes etc. were quite similar to COARE.

Fairall also presented the results of tests of Vaisala sondes by Greg Holland (BMRC) at a site on Willis Island, off the coast of Queensland. Balloons reach a height of about 60m 10secs after launch and about 110m after 20 seconds. At these heights, potential temperature was about 0.5 deg cooler than the surface value, but showed scatter. Humidity, however, was much less scattered and essentially the same for both levels, 1.5-2.0 g kg^{-1} less than the surface value, similar to Fairall's COARE and CSP measurements. However, the situations are not quite comparable; Holland's surface measurement being made at only 3m over land rather than at 15m over sea from a ship.

Paul Ciesielski described the CSU effort to determine atmospheric budgets of heat Q1 and moisture Q2, and the success with which missing and bad sonde wind data been improved by merging the sonde wind data with profiler winds. For the IOP they were able to produce a "merged" data set at seven sites: Kapinga, Kavieng, Manus, Nauru, Kexue #1, Shiyan #3 and Biak. Below 800 mb the percentage of missing or bad wind data was reduced from ~45% to about 20%.The merged dataset is available via anonymous ftp from: tornado.atmos.colostate.edu (129.82.107.215) in the directory /dist/toga/merged_data or at the web site: http://www.joss.ucar.edu/cgi-bin/codiac/ds_projTOGA%20COARE

These data sets were gridded at 1 degree in the horizontal and 25 mb in the vertical to compute atmospheric budgets with two aims: to compare the budgets with other independent measures, and determine their sensitivity to the LLZ correction.

Ciesielski referred to the rainfall estimates by several methods presented by the CSU group at the Woods Hole workshop, and given in tabular form in the report (Bradley and Weller, 1997 p.17). He then discussed the comparison between radar and budget estimates of rainfall, when care is taken to make the sample regions and periods coincident. Using their preferred analyses scheme (multiquadric interpolation, described by Nuss and Titley 1994) they determined the IFA averaged rainfall rate for the IOP to be 8.2 mm day compared to a radar estimate of 4.3 mm day. However, when their budgets are computed just over the radar area (which covers about a third of the IFA) and for same 82 days that the radar was operational, their computed rainfall rate is 4.7 mm day, a much closer estimate to the radar's. For these same 82 days but over the entire IFA, their budget estimate is 6.7 mm day. These results suggest that (a) the radars were situated in a relatively dry region of the IFA, and (b) the 82-day radar exposure was from a relatively dry period of the IOP. Use of the LLZ correction increased their IFA averaged rainfall estimate for the IOP to 8.4 mm day, or an increase of only 2.5%. It appears that the effect of the LLZ correction on the Q2 budget is to decrease the low-level horizontal advection of dry air over the IFA, which reduces the amplitude of negative Q2 (moistening) in the boundary layer.

Ciesielski also examined the surface to mixed layer humidity difference Δq. He showed histograms including all 35 soundings sites, which illustrated the small gradient at VIZ sonde sites, but a wide range from 0.2 - 3.5 g kg^{-1} at the Vaisala sites. Some of this variability between sites may be real, but the difference between VIZ and Vaisala suggests that some is due to differences in sensor performance. LLZ corrections to the ship and Kapinga data restore some uniformity. A similar histogram of RH at 950 mb also confirmed strong instrument bias with VIZ sites being quite moist and Vaisala sites considerably drier. Comparison of the 950mb RH frequency distributions between Kapinga (uncorrected and corrected), Vickers (considered reliable) and Chuuk (VIZ sondes) indicates that conclusions about rainfall, cloudiness and convection at these sites on the basis of the soundings would be very unreliable.

Leslie Hartten reported the work on profiler winds at the NOAA Aeronomy Lab. As reported at the Woods Hole 1996 workshop they have found clutter problems below 700 m on ships Kexue #1 and Shiyan #3 and below 400m at Kapingamarangi. The NOAA Aeronomy and Environmental Technology Laboratories are working with the NCAR Atmospheric Technology Division (ATD) to try and improve corrections so that lower level wind data is available at these sites. Other sites do not appear to suffer these problems.

Dave Parsons was unable to attend, but Dick Johnson outlined the efforts that the ATD group was making to overcome the now-obvious problems with the soundings. The sensor arm heating error had been corrected quite well, but recently ATD has further improved its correction algorithm, based on nighttime pre-launch data, to yield estimates of both sensor arm heating and sensor bias. The cooling (air-conditioning) problem had not been so well corrected. The short-term variability is of concern, but cannot be corrected. Aircraft variances show $\sigma\theta < 0.1$C and σq ~0.3-0.5 g kg^{-1}. Compared with this, scatter greater than 1 g kg^{-1} in the soundings moisture data shown by Zipser is much too high, but it is a mixture of natural variability and instrument error. Since the Woods Hole meeting there had been more analysis to investigate the longer term drifts, which showed a moist bias in December and a dry bias later in Jan.-Feb. Parsons participated in the Japanese Tropical Ocean Climate Study (TOCS) on R/V Kaijo along the equator east of New Guinea, to study the behavior of sondes and try to understand the problems encountered in COARE. The conclusions so far are tentative and not unanimous. The TOCS results were discussed at a workshop at NCAR/ATD about a month after this meeting.

Dick Johnson also presented some new ideas concerning the net tropospheric radiative heating QR over the tropics, which can be obtained as a residual of the Q1 and Q2 budgets. This is a very important point, since independent measurements of QR can be used to estimate the accuracy of the budgets (Yanai et al. 1973). With sensible and latent heat calculated from IMET data using the COARE algorithm, Johnson finds:

IOP/IFA averages	<Q1>	-	<Q2>	=	<QR>	+ S	+ LE
Wm-2	185		117		(-47)	9	106
deg day-1	1.73		1.09		(-0.44)		

i.e., <QR> as a residual is -47 Wm^{-2} or -0.44 deg day^{-1}. This is greater (less cooling) than the clear-sky Dopplick (1972) value of -1.1 deg day^{-1}, as would be expected with cloud cover, and also less cooling than the Thompson et al. (1979) GATE estimate of -0.9 deg day^{-1}. These and other estimates of <QR> are given in Table 1.

Table 1. Net Daily Radiation Estimates over the Tropics

Region	**Conditions**	**Source**	**Method**	**Net Radiation (deg day^{-1})**
Tropics	Clear Sky	Dopplick, 1972	M + M	-1.1
GATE	Clear/Cloudy	Thompson, 1979	Atmos. budgets	-0.9
COARE	Clear Sky Clear/Cloudy	Rossow, personal communication, 1997	M + M	-1.26 -0.88
COARE	Clear/Cloudy	Ackerman, personal communication, 1997	M + M	-0.66
COARE OSA	Clear/Cloudy	CSU, 1997	Atmos. budgets	-0.44 to -0.48
COARE IFA	Clear/Cloudy	CSU, 1997	Atmos. budgets	-0.35 to -0.57
COARE IFA	Clear/Cloudy	CSU+LLZ, 1997	Atmos. budgets	-0.39 to -0.61
M + M = Measurements and radiation Models with assumed moisture and cloud distributions.				

These smaller than expected cooling rates suggest the possibility that the tropospheric radiative characteristics are different from other regions that have been studied. There is supporting evidence for this. For example, Stephens et al. (1994) show that the cloud longwave forcing over the warm pool and eastern Indian Ocean is greater than other locations around the globe. The time series of T’ in Fig. 15 of Lin and Johnson (1996, p.710) shows warming of the upper troposphere as the clouds increase in December. Cloud longwave forcing may account for this warming, but further analysis is ongoing. Up to half the reduction in CAPE in mid-to-late December is explained by this warming aloft. here were many clouds, especially cirrus, in the COARE region and these conditions likely led to a smaller cooling rate than the clear-sky value due to reduction of IR loss.

Johnson indicated that errors in the sounding humidity data would not affect these conclusions (however it cannot be emphasized too strongly that in other contexts, such as cloud modelling or GCM studies, humidity errors have very serious implications). Ciesielski had shown earlier that the effect of the LLZ correction was a small cooling increase of only 0.04 deg day^{-1}. Bill Rossow is working to obtain satisfactory independent computations of <QR>, and the work is continuing by Stephens, Johnson, Webster, and others.

VI. Working Group Reports

1. COARE Soundings Working Group

The purpose of this summary report is to place on record the conclusions and recommendations which emerged from the workshop, to help guide actions which are called for during the coming few months.

In brief, the COARE soundings have accurate temperatures and, with certain exceptions, accurate winds. The wind data are often missing in the lowest 1-2 km, and sometimes in the lowest 3-4 km. The archived dataset linearly interpolates the winds between the first good sounding data point and the surface, with an appropriate flag. A revised version of the wind data is also archived, which incorporates profiler data above ~400-500 meters. This merging procedure is described in Ciesielski et al (1997).

The soundings humidity problem

It is inherently more difficult to attain humidity measurements of the required accuracy. Careful analysis has led to the conclusion that there are systematic humidity errors (biases) in the COARE sounding data that are unacceptably large. Most of this report deals with the humidity issue.

During the initial processing of the TOGA COARE data, it was recognized that in addition to rather large random errors, the sounding humidities were biased in the lowest few hundred meters. Hal Cole and Erik Miller, from NCAR's atmospheric technology Division (ATD) deserve credit for diagnosing this problem, which is known as "sensor arm heating" because most of the apparent errors were that the measurement was too warm near the surface, and for devising a correction. The archived COARE sounding data include this correction.

Unfortunately, it is now quite clear that the sensor arm heating correction, while a step in the right direction, solved just a small part of the humidity bias problem. The following summarizes our current understanding of this issue, which extends beyond the COARE soundings.

We think we know:

1. Sensor arm heating. The Cole-Miller corrections were a good "fix". It is possible that there are additional problems in this category of "environmental contamination". Their importance is unknown and in many cases unknowable. During the TOCS (Tropical Ocean Climate Study) cruise in the west Pacific, systematic experiments were performed in an attempt to reproduce and understand some of these sources of error. These include
    - unknown time intervals, likely differing at each launch site, between removal of the humidity element from desiccant and launch
    - unknown time intervals, likely differing at each launch site, between removal of the sonde from its storage environment and launch
    - unknown conditions of storage at each launch site (e.g., air conditioning)
2. Random errors. These exist and are non-trivial, probably in the range of 3-5%. They are difficult to distinguish from other sources of error, and from natural atmospheric variability.
3. Systematic (bias) errors. These are significant for COARE, often reaching 1 g kg^{-1} (~6% RH) at the warm temperatures and high humidities found in the atmospheric boundary layer. For that

reason alone it is important to recognize and deal with the problem; an error of this magnitude in the lowest 50 mb (hPa) is first order (~50%) in evaluating energy available for convective clouds. The bias errors are probably less serious in the mid-troposphere. (In the upper troposphere, it is well-known that standard humidity measurements are totally unreliable at temperatures colder than about -40°C.)

With a few notable exceptions the sense of the bias is that, for the Vaisala sondes the measurements are too dry, and for the VIZ sondes slightly too moist, in the boundary layer. This is true not just for the IFA (Intensive Flux Array) region, but for most of the 35 sites in the extended COARE array which have been examined to date, covering most of the warm pool. (Data which demonstrate these conclusions are extensive, and will be presented as part of a manuscript in preparation for the Bulletin of the American Meteorological Society by E. Zipser, C. Lucas, R. Johnson, P. Ciesielski, M. LeMone, D. Parsons, H. Cole, E. Miller, C. Fairall, and perhaps others).

We know enough to adjust the soundings in a way that will reduce these systematic errors. The procedure used by Lucas, LeMone and Zipser (LLZ) is based upon the principle that the atmospheric boundary layer humidity is linked systematically to the surface layer humidity most of the time. We believe that in most cases the surface humidity data is more accurate than the boundary layer humidity data from the soundings, thereby permitting an adjustment which will, on average, remove much of the bias. Of course, it is painfully clear that any such adjustment will come at the expense of some real atmospheric variability. Therefore, while the principle of the suggested adjustment is accepted, the decision on a specific algorithm for its implementation is subjective, to some extent.

Recommendations:

1. There are many users who are awaiting a new version of the COARE sounding data. Therefore, our decision on adjustments to the COARE humidity data should be made and implemented soon. 15 August 1997 is our suggested completion date.

2. The TOCS cruise obtained more than 170 soundings over the warm pool, and there was a concerted effort to understand the nature of the sounding errors, through carefully controlled launch procedures and comparison of surface, kite, tethered balloon, and sounding data. An informal workshop on the TOCS results is planned for mid-June. Lessons learned from TOCS should be summarized at that workshop and used to help decide on the correction algorithm for COARE soundings.

3. The correction developed by LLZ, while basically OK, should be treated as “first guess input” to an improved algorithm.

4. We have obtained sonde calibration data from several sources, and they should be taken into consideration in an improved algorithm. The manufacturers of the sondes should be entrained into this process but, if necessary, we should proceed independently.

5. NCAR’s Atmospheric Technology Division (ATD) is in the best position to take the leadership role in the process during the next 3 months, to develop and serve as a clearing house for all inputs, and to implement the adjustment algorithm.

6. Because the adjustment algorithm will probably be based on the surface observations, it is very important to undertake a quick-look quality control procedure on the surface data. In addition,

while we believe that adjustments based upon surface humidity data will result in improvements to the sonde data, these must be undertaken with caution outside the IFA (for which the LLZ scheme was developed), especially for sounding sites on large land masses with correspondingly large diurnal cycles.

7. There should be widespread e-mail and web page notification to the COARE scientific community of the findings of this Working Group, including a time estimate of when a new version of the COARE sounding data is expected.

8. Scientists at the NOAA Aeronomy Lab are looking into the possibility that the profiler winds could be extended downward from 700 to ~500 m at Ships 1 and 3, and from 400 to ~300 m at Kapinga. While encouraging this effort, a resolution of the feasibility, priority, and cost of implementation is not expected within 3 months, so we suggest treating this matter independently of the humidity bias issue.

Timetable for corrections

Following the workshop, activity on the soundings correction issue developed rapidly. On August 12 Ed Zipser circulated a note to the soundings group updating the status of arrangements with NCAR/ATD negotiated by himself and Dick Johnson. There is now some optimism that soundings biases can be corrected objectively using recorded pre-launch data, but this probably has to be done on a sounding-by-sounding basis. Inevitably, this will be time-consuming and requires the availability of sufficiently skilled personnel to do the work. However, the following tentative timetable was proposed at a meeting between Ed, Dick and Dave Carlson (Director ATD);

By September 1 - prepare correction algorithms for H-sensor at 4 ISS sites of Manus, Kavieng, Xexue #1 and Shiyan #3.

By October or November - prepare correction algorithms for air-conditioned launch ISS sites Kapingamarangi and Nauru. Prepare correction algorithms for A-sensors used briefly at several ISS sites (Manus and Nauru).

By end of 1997 or early 1988 - apply and evaluate the corrections at all ISS sites. Provide these data for community use. Propose a mechanism and schedule for corrections to other PSS sites.

Later in 1998 - Complete corrections to other PSS sites and make available for community use.

Dick Johnson and Ed Zipser will maintain contact with ATD and report to the group again on or before 13 October 1997. On the one hand, it is disappointing that the task of correcting the COARE soundings is taking so long. On the other, we can hardly expect that these anomalies are specific to COARE, and the implications and importance of this massive effort by the Soundings Group go well beyond our own needs for accurate data from atmospheric soundings.

2. GEWEX Cloud System Study (GCSS) Working Group on Precipitating Convective Cloud Systems: TOGA COARE Studies

The strategic goal of GCSS is to advance the parameterization of cloud-related processes in general circulation models (GCMs) and numerical weather prediction (NWP) models through an improved physical understanding of these processes and their interaction. The main tool of GCSS is the cloud-resolving model (CRM), which is a numerical model that resolves cloud-scale (and mesoscale) circulations. In contrast, neither GCMs nor NWP models can resolve the individual convective cells or even the accompanying mesoscale circulations. Therefore, the collective effects of these sub-grid-scale processes must be parameterized. A CRM is able to determine these collective effects directly, to the extent that its representation of grid-scale dynamics and the parameterizations of its own sub-grid processes are accurate. The strategy for accomplishing this goal as far as precipitating convective cloud systems is concerned, is detailed in Moncrieff et al. (1997).

In generic terms a CRM is a fine-scale, non-hydrostatic numerical model but we identify two categories in terms of the type of problem each addresses. First, the process-oriented model (the classical ‘cloud model’) has been weakly coupled to the large-scale fields through open lateral boundary conditions (c.f. the two CRM types in Tao’s presentation in section IV). Initial profiles of thermodynamics and velocity can be either idealized or specified from soundings. It is initialized in several ways, such as with a cool pool, a warm bubble, surface fluxes, surface temperature (e.g., SST) or random perturbations. This type of CRM is used in GCSS WG4 CASE 1 described below. The second type of CRM is used to study the role of cloud systems in climate, for example, in GCSS WG4 CASE 2 described below. Because it explicitly resolves cloud-scale circulations (hence its name) it is clearly distinguished from the general circulation model (GCM), in which cloud-scale processes must be parameterized. In other words, the key advantage of the second type of CRM is that although the processes of radiation, turbulence, surface processes and turbulence must be parameterized, cloud-scale circulations which locally couple these processes, and gravity waves which carry cloud-scale effects to the far field, are explicitly resolved. Two-dimensional CRMs presently have domains up to several thousand kilometers and be run for up to intraseasonal time scales. Three-dimensional CRMs have domains several hundred kilometers on a side and can be integrated for up to a week or so. This range of motion scales is of key importance to the cloud-climate problem.

It is worth noting that CRMs are limited area models and lateral boundary conditions are needed to couple the models to the large scale, but there is no fully satisfactory way to accomplish this. Presently, the GCSS intercomparison studies typically use either open lateral boundary conditions (CASE 1) or periodic conditions (CASE 2). Note that CASE 2 seeks a statistical realization of cloud systems as required for parameterization, because convection is not deterministic on long time scales. On the other hand, CASE 1 is basically an initial value problem in which the structure of convective systems is being evaluated in an essentially deterministic fashion.

Parameterizations are implemented in GCMs and NWP models in one-dimensional (columnar) fashion, which gave rise to the term “single-column model” (SCM), as reviewed by Randall et al. (1996). Thus, a practicable way to develop parameterizations is by combining the SCM and CRM approaches, and this combination is being followed in GCSS.

GCSS Working Group 4 recently initiated two projects to evaluate CRMs using TOGA COARE data sets (Moncrieff et al. 1997). The first (CASE 1) is a detailed study of a squall line cloud system on a time-scale of hours. The second (CASE 2) is the multi-day evolution of cloud systems; that is, on a time scale where the key issue is the interaction among processes, rather than any single process. CASE 2 was forced by evolving large-scale advection of temperature, moisture and wind. The fact that the modeled cloud systems evolve spontaneously in concert with the large-scale conditions is important for parameterization studies. Although a link between cloud system dynamics, transport properties and large-scale quantities (e.g., shear) has been theoretically quantified (Moncrieff 1981), only recently have numerical models been capable of spontaneously generating cloud systems and transitions (including Wu and Moncrieff 1996, Wu et al. 1997a,b).

CASE 1: Squall line study

This is a detailed simulation and evaluation against observations of a squall line with a trailing stratiform region. The simulation results are used to test, first, how well CRMs can realize cloud systems and, second, how the CRM simulations can improve convective parameterization schemes. All three principal components of convective parameterization need to be evaluated: (i) the trigger function which determines when a scheme should be activated, (ii) the source/sink/transport function, and (iii) the closure which represents the amplitude of the convective effect on the environment. In addition, other cloud-related aspects need to be evaluated, including the cloud water content needed for prognostic cloud schemes.

Specifically, CASE 1 concerns a 100 km-long squall line observed during COARE on the 22 February 1993. It was well-sampled by airborne Doppler radar during the mature and decaying stages of its life cycle. The squall line was observed to be oriented nearly perpendicular to the low-level shear vector, traveling at a speed of 12 m s^{-1}. At low-levels, a drop of 15 K of equivalent potential temperature was observed across the leading edge. The 3-D fields of wind and reflectivity obtained from the Doppler radar can be compared with simulations to evaluate if 3-D CRMs reproduce the structure and evolution of an observed cloud system.

Two-dimensional and three-dimensional simulations were performed on CASE 1 with seven different CRMs. Sensitivity tests to microphysical parameterization, surface fluxes, radiation, domain size and dimensionality of domain (i.e. 2-D *vs* 3-D) have been realized. Three single-column models (SCM) were used, and one tested four different parameterization schemes. Overall, cloud-resolving models are able to simulate the gross observed features of the squall line (e.g. mean precipitation structure and speed of propagation). Ice parameterization seems necessary for a significant development of the stratiform region.

All 3-D models that include a parameterization of ice phase are able to simulate the different stages of squall line. Horizontal flow at low- and mid-levels in both Doppler observations and simulations indicates that horizontal vortices form at the North and South parts of the squall line. The line-averaged vertical motion detailed from Doppler radar measurements during the linear stage indicates a double-peaked updraft structure. This feature is also simulated. The second peak around 10 km height was obtained only when the ice phase parameterization was turned on. 2-D simulations with ice phase parameterization also exhibit this structure. If surface fluxes and/or radiative processes are included, a slight increase of the intensity is obtained. Comparison of time series of total ground rain again shows that 2-D experiments have larger temporal variability than three-dimensional experiments. Ice processes, surface fluxes and radiative processes increase the surface rain.

Simulations with SCMs using specified large scale forcing show a general agreement for the predicted ground rain with 3-D CRMs. One difference is at the earlier stages of numerical experiments. Some convective schemes used in SCMs instantly trigger the convection, while in others triggering is delayed which is in better agreement with the CRM. This feature will be studied further and could lead to an improvement of the triggering function used in the convective parameterization.

While convective momentum transport has often been modeled (especially for squall lines) much uncertainty remains concerning its parameterization. A good agreement for the normal wind is obtained for 3-D simulations, though closer analysis of results show that ice processes are seemingly important. Ice processes change the vertical circulation and consequently the horizontal momentum transport. The comparison of momentum transport profiles between the 2-D and 3-D simulations indicates important differences, indicating that the momentum transport is basically three-dimensional in CASE 1. This is interesting because sometimes there is much better agreement between two- and three-dimensional results (e.g., west African squall lines). Note that the squall lines in COARE were much more transient than those in west Africa. Clearly there is a need for further investigation.

The thermodynamic impact of a squall line is classically investigated by examining the apparent source of heat (called Q1 in convective parameterization). To better compare results, the quantities have been normalized by the total surface rainfall. Analysis of results lead to similar conclusions to the above in regard to the importance of ice phase and dimensionality of model framework. For the more complete simulations, the profile shows a maximum heating of about 10 deg cm^{-1} (heating is expressed in deg day^{-1} and normalized by rain expressed in cm day^{-1}) located around 7~km. The heating is mainly due to the latent heat release, although convective transports are significant mainly below 2~km where they reduce the subcloud evaporation of precipitating droplets and the net condensation between 1 and 2~km. Results obtained from SCMs show an overall behavior similar to the reference CRM simulations. Looking more closely, several faults occur and will be studied in the coming year; for example, unexplained behavior for some schemes near the melting level (height ~4km) and different structures ii the upper troposphere.

CASE 2: Multi-day Simulations in Evolving Forcing

This intercomparison project evaluates CRMs by testing their ability to determine the large-scale (domain and time-averaged) statistics of precipitating convective cloud systems (Krueger et al. 1996). To make a useful comparison of CRM simulations and observations, the models simulate a multiday period. We selected a 6-day period from TOGA COARE (20 - 26 December 1992), which included several episodes of deep convection. The large-scale quantities required for the CRM simulations (initial conditions, upper and lower boundary conditions, and large-scale advective tendencies of potential temperature and water vapor) are based on observations averaged over the IFA (about 500 km by 500 km).

Preliminary results from several models were submitted for intercomparison at the GCSS Working Group 4 meetings that took place during October 1996 in Annapolis, Maryland, and May 1997 in Boulder, Colorado. The participating models included five 2-D CRMs, one 3-D CRM, one 3-D mesoscale model, and five single-column models (SCMs). The submitted results have been evaluated using the large-scale (average) properties observed over the entire TOGA COARE IFA. Krueger (1997a,b) contains further details and preliminary results, while Wu et al. (1997) describes the observational datasets used. Results can be accessed using a web browser or by ftp (ftp://ftp.met.utah.edu/pub/skrueger/gcss_wg4_case2).

The similarities among different CRMs for temperature, precipitable water, outgoing longwave radiation (OLR), ice water path (IWP), cloud mass flux, and many semi-quantities, confirms that the bulk characteristics of convection are determined (in a quasi-diagnostic sense) by the large-scale advective tendencies, and that CRMs are useful tools. For example, the IWP is strongly modulated in a consistent pattern in all the simulations. Furthermore, the evolution of the simulated cloud mass flux is very similar to that of the IWP, which suggests that the IWP due to cumulus convection is basically parameterizable.

Results and observations are available for the time series of large-scale temperature and water vapor mixing ratio profiles, surface turbulent fluxes of sensible heat and latent heat, surface downwelling solar and infrared radiative fluxes, top-of-atmosphere (TOA) upwelling solar and infrared radiative fluxes, satellite-derived cloud amount, and surface rainfall rate.

In addition, time series of model results were submitted for many quantities for which observations are not available, including the convective and stratiform fractional areas, and the large-scale profiles of cloud water, cloud ice, rain, snow, and graupel mixing ratios, cloud fraction, solar radiative heating rate, infrared radiative heating rate, updraft cloud mass flux, downdraft cloud mass flux, average updraft core speed, and average downdraft core speed.

Differences between the CRM simulations and the observations may occur due to unrealistic aspects of the model formulations and/or observational limitations. All models developed a cold bias of about 2 K with a similar evolution. This is hypothesized to be largely due to errors in the imposed large-scale forcing (including perhaps having to assume no horizontal advection of condensate due to lack of observations). We are checking this hypothesis by careful analysis of the tropospheric budget of moist static energy. This requires accurate measurements of the vertically-integrated radiative heating rate and the surface sensible and latent heat fluxes over the IFA.

One 2-D CRM has been tested against all 18 days of the GATE dataset (Xu and Randall 1996). Another 2-D CRM has been tested using a 7-day period of the GATE dataset (Grabowski et al. 1996) and a 39-day period of the TOGA COARE dataset (Wu et al. 1997a). A 3-D version of this CRM has also been run for the same 7-day period of the GATE dataset (Grabowski et al. 1997) and for a 7-day period during COARE (Wu et al. 1997a). The temperature errors for these two CRMs were somewhat less for the GATE simulations than for Case 2. One explanation is that the accuracy of the temperature, humidity, and wind observations made during TOGA COARE is less than those made during GATE (due to the lower station density and launch frequency of the rawinsondes), but there are other possible reasons, for example, the lack of condensate forcing (Wu et al. 1997).

The TOGA COARE IFA winds have been re-analyzed recently by merging profiler and rawinsonde measurements (Ciesielski et al. 1997). Simulations using the revised IFA analyses were made to gauge the impact of the merged winds on the simulated temperature and water vapor fields. The revised analyses produced no significant differences.

CASE 2: Sensitivity studies

Results from a number of sensitivity studies related to Case 2 were also presented at the May 1997 workshop. Summaries of the results follow.

Kerry Emanuel used the tropospheric moist enthalpy conservation equation, along with the imposed (analyzed) large-scale advective tendencies of moist enthalpy over the IFA, the observed surface fluxes of moist enthalpy over the IFA, and an estimate of the tropospheric radiative heating rate over the IFA, to show that the troposphere must cool and/or dry substantially over the six-day period of Case 2.

Jonathan Petch used a SCM to study the effects of using the observed large-scale (i.e., IFA average) vertical motion and the model-predicted vertical gradients (instead of the observed vertical gradients) to calculate the large-scale vertical advection of potential temperature and water vapor for Case 2. He found that this approach tended to amplify fluctuations when the large-scale flow is convergent.

Wojciech Grabowski showed the results of three sets of 7-day GATE 2-D CRM simulations that included (1) small perturbations, (2) changes to the microphysics parameterization (with fixed radiative heating rates), and (3) changes to the microphysics parameterization (with interactive radiative heating rates). He found that the resulting changes in mean relative humidity were less than 6 percent in all cases.

Francoise Guichard showed the results of two 2-D CRM Case 2 simulations with different surface fluxes (about 10 percent different). Only small differences in the temperature and water vapor fields resulted.

Wei-Kuo Tao showed the results of using a two-ice-class versus a three-ice-class microphysics scheme in 2-D CRM (but not Case 2) simulations. There was a 10 percent decrease in precipitation with the two-ice-class scheme.

Leo Donner showed 2-D versus 3-D CRM simulation results for an idealized case. The 2-D results show more temporal variability and a different CAPE evolution. He also showed the effects of including radiative heating; there was little effect on precipitation for the case considered.

Discussion

WG 4 discussed the following issues:

1. How can the Case 1 and 2 CRM results be used to help test/improve SCMs (and their constituent parameterizations)?
2. How can the Case 1 and Case 2 evaluations of CRM simulations using observations be used to improve CRMs? In particular, what aspects of CRMs are in most need of improvement, in the context of the goals of GCSS?

Results of the discussion:

1. To focus on the SCM parameterizations of convection and cloudiness, it was proposed to supply the following for SCMs for Case 2: the time-evolving IFA-averaged radiative heating profile (CRM-derived that best matches the observed TOA and surface radiative fluxes), the observed IFA-averaged surface fluxes of sensible and latent heat, and large-scale vertical advective tendencies of potential temperature and water vapor that satisfy the constraint of the observed IFA-averaged tropospheric moist static energy budget. Consensus results from several CRM simulations with the same forcing will be provided for evaluation of the SCMs. Such results will include the evolving profiles of the cloud mass flux, cloud fraction, cloud water content, ice water content, and other quantities that SCMs predict but are difficult to measure.
2. Case 1 and Case 2 are examples of two approaches for evaluating CRMs. Case 1 relies primarily

on aircraft (including airborne radar) observations, while Case 2 depends more on the IFA array of rawinsondes, island, ship, and buoy surface measurements, and satellite measurements and retrievals. Case 1 focuses on the ability to simulate the mesoscale structure of a single cloud system, while Case 2 aims to simulate the large-scale properties of many cloud systems. At least for Case 2, additional measurements are available which should be acquired and used to further evaluate the CRMs. These include surface radiation measurements, additional satellite TOA measurements (including SSM/I measurements and distributions of cloud top temperature, etc.), ship radar data on the statistics of convection over a sub-region of the IFA, wind profiler statistics on the vertical distribution of hydrometer properties, all-sky cloud photographs, and ceilometer data on cloud base heights and frequencies. In addition, observations of the IFA-averaged profiles of cloud liquid water or cloud ice, or their vertical integrals, the liquid water path or ice water path, are needed to further evaluate and improve CRMs.

VII. Mapping reports

1. Flux mapping

An objective of the flux working group is the integration of observations into spatial fields on the scale of the IFA and larger domains. These maps are intended to provide basic insight into the spatial and temporal variability of the surface fields and to provide input to or verification of ocean and atmospheric models. Neither the data, nor the models alone are sufficient to completely resolve the physical structure of the COARE region. The variability of the observed fields is a critical test of the scales that must be resolved in model applications. The model response is a useful test of the ability of numerical codes to resolve adequately the physical processes that control the coupled ocean-atmosphere system. The mapping exercise covers numerous scales and existing data sets. Major difficulties remain in trying to resolve features on scales poorly represented in the data and in matching information obtained at a variety of scales.

As a minimum requirement, maps should be available at two scales, as suggested by Bob Weller at the Woods Hole workshop in October 1996 (Bradley and Weller, 1997):

Numerical Weather Prediction (NWP) / Climatology grid scale

- 1° spatial resolution
- available 4 times per day for the warm pool region and the western tropical Pacific

High resolution products

- 1 km and 10 minute resolution
- available for the Intensive Flux Array

2. Sea surface temperature (SST) and sea surface salinity (SSS)

Several sea surface temperature products exist, or are in the pipeline. These fields are available at various spatial and temporal scales from a variety of sensors and techniques. Satellite derived fields are available at 1 km and 4 km resolution, but with low temporal resolution. The best coverage is available as monthly averages, but data are available daily, and from 10 and 14 day averages. These data suffer from the need to remove cloud contamination, which can reduce the number of useful pixels. A 50-km SST product will be produced as part of the ISCCP data set referred to in 4. below. Currently these data are available three-hourly on a 2.5 degree grid.

Maps of surface temperature and salinity near the center of the IFA can be constructed by use of *in situ* measurements from buoys and ships. Clayton Paulson outlined the work done at OSU by himself, Jane Huyer and Lynn deWitt on obtaining SST maps based on R/V Wecoma surveys, WHOI buoy measurements, and the COARE bulk flux algorithm. The Wecoma surveyed along 135-km butterfly tracks with center near the WHOI buoy. The Wecoma data were used to compute meridional and zonal temperature gradients at an “optimum” depth (of order 10 m) which is minimally effected by diurnal heating and oceanic internal waves. Surface skin temperature at the WHOI buoy was estimated by use of the COARE bulk flux algorithm with input from buoy measurements of meteorological variables and temperature at the optimum depth. The horizontal temperature gradients at optimum depth were then used to extend the point estimates of SST at the buoy over the area of the Wecoma butterfly. These SST products will be available by December 1997. It was pointed out that the method used to estimate SST could be used to estimate SSS by modifying the COARE bulk flux algorithm and using the radar rainfall fields as input. It was also noted that the R/

V Noroit made several meridional surveys during the IOP, which could be used to estimate meridional variation of SST. A similar procedure can be used for salinity; in this case fresh water inputs from rain rather than diurnal heating must be considered.

3. Surface currents

Current fields are available directly from Wecoma butterfly pattern surveys in the vicinity of the IMET buoy. Peter Hacker (U. of Hawaii) has prepared a data set consisting of IMET and Wecoma current data. It is available from the U. of Hawaii and also part of the data archive. The Price, Weller and Pinkel (PWP) model is used to correct subsurface measurements to surface currents, the correction being typically 5 cm sec^{-1}. Hacker showed time series of the product, and drew attention to Jan. 9-20 when IMET was on the edge of a large eddy. The domain will be extended with the Noroit N-S transect data.

Gary Lagerloef is developing ocean current maps at 1 degree resolution for the entire Pacific basin extending from 25S-25N, based on sea level gradients derived from TOPEX/POSEIDON altimetry data and Levitus climatology, FNOC/NOGAPS winds and a steady-state regression model. 10-day smoothed currents are produced, calculated at 15 m depth to correspond with drifter drogue depth. Generally, they compare well with currents indicated by the *in situ* drifter positions for the period October 1992 through December 1994.

4. Radiation and cloud fields

Bill Rossow described the radiation and cloud analyses being made at NASA/GISS. The primary product is the International Satellite Cloud Climatology Project (ISCCP) data set which provides standard cloud and radiation gridded parameters on a scale of 2.5 degrees covering the equatorial Pacific (20 S to 20 N and 120 E to 170 W. Improvements to the radiation code include:

1. Aerosol correction on surface reflectance
2. Non unity emissivity correction on surface skin temperature
3. Better interpolating surface air temperature
4. Increasing resolution in K-distribution parameterization
5. Adding Fractal ice-cloud microphysical model
6. Updating aerosol climatology
7. New surface albedo climatology
8. Improving water continuum parameterization
9. Implementing use of particle size climatology
10. Adding diurnal variability to TOVS air-sea temperature difference
11. Inhomogeneous cloud parameterization
12. Updating cloud vertical structure climatology

The following COARE related projects at NASA/GISS are underway:

1. Validation of ISCCP cloud products: cloud cover, top temperature, optical thickness, cirrus cloud properties, diurnal variations, annual cycle, global and El Nino variations.
2. Validation of ISCCP SST retrieval and testing of an experimental SST retrieval.
3. Analysis of cloud property evolution in mesoscale convective complexes

4. Study of cloud vertical structures
5. Diagnosis of surface and top-of-the atmosphere radiative fluxes and the effects of water vapor and clouds on them.
6. Sampling studies with high space-time resolution surface solar insolations
7. Diagnosis of radiative heating profiles in the atmosphere
8. Diagnosis of surface energy fluxes into the ocean and the inferred ocean heat transport.

Rossow pointed out that the data set is in the TOGA-COARE archive, with a full description (see the COARE Data Information System), and also recommends referring to their web homepage at: http://isccp.giss.nasa.gov/

He also indicated plans to re-analyze the entire COARE domain at a resolution of 0.5 degrees. Rossow's colleague, Yuanchong Zhang, showed examples comparing maps at 2.5 degree and 0.5 degree resolution; the differences in some cases were very dramatic.

5. Aircraft flux maps

A limited set of eddy-covariance flux maps has been computed from the turboprop aircraft. Three aircraft flown together provide sufficient temporal resolution to map almost the entire IFA. Though small scale they provide the only direct, nearly instantaneous, measurements of the spatial variability of the surface fields. The fields include SST, air temperature, humidity, winds and the fluxes of heat, moisture and momentum. Bulk estimates from the mean variables enable a direct comparison with the eddy correlation fluxes. Work on these fields is ongoing at UCI (Friehe, Khelif, Burns), SIO (David Rogers) and at UW (Yolande Serra) as time permits.

6. Rainfall fields

Dave Short reminded the meeting that merged radar rainfall rates are available from the TRMM web site (trmm.gsfc.nasa.gov) on a 2-km by 2-km grid every 10 minutes, with a convective and stratiform cloud identifier. He went on to describe the continuing effort by himself and Paul Kucera (now at University of Iowa) to relate the radar rainrates to ORG measurements on the Xiang #5. Centering a 2x2 km pixel grid over the ship, and restricting to times when the ship was drifting and rainrates greater than 0.5 mm hr^{-1}, agreement between the statistics of radar and ORG rainfall improved significantly as the ORG averaging period was increased from 1 through 4 to 8 minutes. At 8 mins agreement was excellent over the range to 100 mm hr^{-1}. Similar comparisons for R/V Franklin, described in the Woods Hole report (Bradley and Weller, 1997), gave agreement within 25%, for individual storms with rainrates between 20 and 100 mm hr, allowing for a 5-minute raindrop fall time.

Short also reported new intercomparisons by Riko Oki using data from the Keifu-maru for the 10-day period when the 250km range radar overlapped Kapingamarangi atoll and the two COARE radars. A post-experiment calibration had indicated a need for correction of the Keifu's radar data by -7.1 dbZ. This produced good agreement between the MIT and Keifu radars over the period Nov. 10-12 during two storms with a peak rainrates of 2-3 mm hr^{-1}. At the same time, the COARE radar on Xiang #5 actually recorded lower rainfall, because heavy rain falling directly over the ship caused signal attenuation. At Kapingamarangi, the Keifu radar measured about double the amount of rain recorded by the tipping bucket and disdrometer. Comparison with the 915 Mhz profiler reflectivities

(Gage, Williams, et al) suggests the discrepancy is due to radar bright-band effect (caused by ice crystals) at around 4-5 km height and perhaps substantial evaporation from falling droplets toward the end of the storm event. Note also the results presented by Ciesielski in section V, indicating that the MIT and COARE radars were located in a relatively dry region of the IFA, during a relatively dry period of the IOP.

Chris Williams showed examples of the profiler data at Kapingamarangi, and pointed out discrepancies between the GMS satellite IR imagery, and raingauge results where cold cloud exists. The Jan 26 rainfall event was a good example. The Williams/Gage profiler data sets will be available shortly, and they will seek feedback from users, particularly the modeling community.

VIII. Flux Data Reports

1. Aircraft correction set

The group at UCI (Carl Friehe, Djamal Khelif, and Sean Burns) has spent considerable time and effort studying the performance of the various sensors on the aircraft. Initially, they provided a very preliminary set of "primitive" offsets around May 1994 in time for the Toulouse data workshop. In March 1996 Sean circulated a memo to the COARE community, containing a revised and more comprehensive table of offsets, which may still be accessed on:

http://wave.eng.uci.edu/Projects/Toga_Cepex/Documents/offsets_email.txt

At this workshop Djamal presented a further, and probably final, revision to the aircraft correction set dealing comprehensively with all instruments, including redundant sensors where applicable. The analysis compared aircraft vs aircraft, and aircraft vs ships and buoys, and included data from the two P3s, the Electra, the UK C130 and Flinders Cessna 340A. Tables and graphs were presented, with the statistics of comparisons in the form of "box plots". A draft manuscript of the complete study is almost completed for submission to the Journal of Atmospheric and Oceanic Technology. Rather than try and summarize the very extensive results in this report, Djamal has kindly provided access to the postscript file for this set of corrections, release date given as March 8 1997: http://wave.eng.uci.edu/Projects/Toga_Cepex/tc_offsets.ps

A full history on the different data releases by UCI can be found at: http://wave.eng.uci.edu/Projects/Toga_Cepex//togacoare.html

2. Turbulence flux data sets

The exchange coefficients used in the COARE bulk flux algorithm were initially "tuned" to agree on average with the direct eddy-fluxes measured from the Moana Wave. At the Honolulu workshop in 1995 (Bradley and Weller, 1995b), the Wave fluxes were modified slightly and augmented with data from other ships. While they were used as a guide, the aircraft data were not included in this process, partly because of the possibility of flux divergence below flight level, even at the lowest heights, and partly because historically exchange coefficients have been defined from ships. It was agreed that a combined ship turbulence set should be assembled. There was some discussion about whether tropical data from cruises other than COARE and in other tropical locations should be included. A list of all appropriate data sets was compiled as shown in Table 2.

3. Data archives

At the Woods Hole workshop in October 1996, Richard Chinman provided an overview of the COARE data management and archiving situation. He pointed out that the data management function provided by TCIPO formally ceased with the closure of the office in June 1996; at precisely the time when new and corrected data sets were becoming available. Within the COARE community, and the Flux Group in particular, updated data sets are often made available via the Web on a personal request basis. But some data users have (and never learn otherwise) early and erroneous data sets. (How many of us have reviewed manuscripts based on COARE data, and thought "Oh dear, I wonder if they know about Sean Burns' corrections to these Electra measurements?")

Table 2

Observer	Experiment	Vessel	Location	Fluxes
Bradley	COARE	Franklin	West Pacific	H, E
Fairall	COARE	Moana Wave	West Pacific	H, E, τ
Ishida	COARE	Hakuho-maru	West Pacific	H, E
Song	COARE	Kexue #1	West Pacific	H, E, τ
Other tropical				
Bradley	MCTEX	Franklin	Timor Sea	H, E, τ
Bradley	BASICS	Franklin	Bismarck sea	H, E, τ
Fairall	TIWI	Moana Wave	West Pacific	H, E, τ
Fairall	CSP	Discoverer	West Pacific	H, E
Midlatitude				
Fairall	SCOPE	FLIP	California	H, E, τ
Fairall	ASTEX	Baldrige	Azores	H, E, τ
Fairall	MBL	Wecoma	Monterey	H, E, τ

Notwithstanding the formal closure of TCIPO, since WHOI96 Chinman and Jeanette Walters have worked to secure permanent archive arrangements for most of COARE data. All available COARE datasets have been transferred to the specialized data centers (FSU, Penn. State, PMEL etc.), but in addition the original meteorological and oceanographic datasets have been archived at NCDC (Asheville NC) and NODC (Silver Spring MD). All COARE datasets have also been sent to the deep archive at NCAR in Boulder CO.

Also, within the past year, the Data Information Unit at University of Delaware came to the end of its planned period of operation. Jeanette Walters therefore took the opportunity, as the datasets were transferred to NCDC and NODC, to revise the format and content of the data catalogue. This is now called the TOGA COARE Data Information System, accessed at: http://www.ncdc.noaa.gov/coare

Accessing this site provides a list and contact information (URLs or ftp addresses) for the permanent COARE data centers. However the most valuable link is to the new COARE Data Users Guide, being a description of all available datasets organized by platform, with links to the center(s) where the data are archived.

Richard Chinman demonstrated the various steps in using the new system. With Jeanette's departure from UCAR, information about the system, access to archived products or the method of lodging or updating datasets will be handled by David Bowman (dbowman@ncdc,noaa.gov) who has worked with Jeanette during the transition and is the point of contact at NCDC.

4. COARE flux bulk algorithm

At the Woods Hole workshop, 9-11 October 1996 (Bradley and Weller, 1997) it was agreed that no further development would be attempted to the community version of the COARE Bulk Flux Algorithm, and that a version 2.5b bulk algorithm "package" would be made available, consisting of the FORTRAN source code and a test data set. This was released at the workshop, and is now available from the following archive sites:

1. The Florida State University COAPS (Center for Ocean Atmospheric Prediction Studies):
http://www.coaps.fsu.edu/COARE/flux_algor/
OR
ftp://coaremet.fsu.edu/pub/coare/flux_algor/

2. Scripps Institution of Oceanography Physical Oceanography Research Division:
http://penarth.ucsd.edu/coare/
OR
ftp://penarth.ucsd.edu/coare/

3. NCAR (National Center for Atmospheric Research) Data Support Section:
http://www.scd.ucar.edu/dss/datasets/ds606.1.html

The COARE Data Information System at http://www.ncdc.noaa.gov/coare has pointers to each of these sites.

Frank Bradley gave a brief description of the "package" which consists of three files:

coar2_5b.for	33K	(FORTRAN source code)
test2_5b.dat	12K	(Test data set)
test2_5b.out	14K	(Output file from test data)

A full description of the code and the test data set appears at the head of the FORTRAN file and includes the following information:

1. The input "read" statement is set up for the test data file test2_5b.dat . This consists of four days of Moana Wave COARE data, 26-29 Nov 1992, prepared from Chris Fairall's hourly data file wavhr2_5.asc dated 31/10/96. A full description of the Moana Wave operations, instruments and data set is given at:

   http://www.ncdc.noaa.gov/coare/catalog/data/air_sea_fluxes/moana_flux.html

2. Only those parameters required by the flux algorithm were extracted from Chris' lines of data, excepting that his independently calculated bulk fluxes are included for comparison.

3. Some parameters are not input, but must be redefined in the code if necessary (e.g., the height of sensors (hum, htm), the bulk ocean mixed layer temperature sensor depth (ts_depth), needed for calculation of the warm layer effect, and pressure and mixed layer height (pp and zi) if available).

4. Because Chris' Tsea was measured at only 0.05m depth, we have added Ts at 6m depth from Mike Gregg's Advanced Microstructure Profiler (AMP, but headed MSP in the file) to demonstrate the warm layer code. The Profiler was operated from the Moana Wave during leg 1, and the data was kindly provided in suitable form for the test file by Hemantha Wijesekera (Oceanography Dept., Oregon State University).

5. The warm layer and/or cool skin code may be bypassed by setting jwarm and/or jcool to zero in the code.

6. To demonstrate the warm layer and cool skin, we output the respective delta-temperatures and the warm layer thickness. Note that dt_warm is the warming across the entire warm layer. Only if tk_pwp is less than the sensor depth (ts_depth = 6m in the test case) will T0=ts-dt_cool+dt_warm. Otherwise, a linear profile is assumed, and the appropriate fraction of warming above the bulk sensor calculated. Chris' Tsea at 0.05m depth will generally include

most of the warm layer but not the cool skin effect.

7. The Webb correction (Webb et al. 1980) to latent heat flux and the sensible heat flux due to rainfall (Gosnell et al. 1995) are NOT added to these fluxes internally in the code. They are output separately, and may be accounted for at the user's discretion.

Discussion

Ken Sperber (NEG-1) expressed some concern that further work on the COARE bulk flux algorithm would cease, particularly given that it had not been verified above windspeeds of about 12 m s^{-1} (later, in an effort to perhaps spur further development of the flux code and the development of convective schemes from COARE data, during the discussion of COARE98 Sperber proposed a session on "Parameterization Development and Applications." (see below.)

Applications of TOGA COARE bulk algorithm

The formalism of the algorithm and the warm layer and cool skin physics are fully described in Fairall et al.(1996a, b). The last major modifications were made at the COARE Air-Sea Interaction (Flux) Group Workshop in Honolulu, 2-4 August 1995 (Bradley and Weller, 1995b). Transfer coefficients were adjusted by six percent to give better average agreement with covariance latent heat fluxes from several COARE ships. This produced version 2.5b, which has been used successfully on various ocean-atmosphere field campaigns by members of the Flux Group, at various locations and from a variety of platforms.

For general information, Chris Fairall has provided the following list of publications he has come across, where the COARE algorithm has been used:

Anderson, S. P., R. A. Weller, and R. Lukas, 1996: Surface forcing and the mixed layer in the warm pool: Observations and 1-D model results. *J. Clim.*, **9**, 3056-3085 .

Babin, S. M., G. S. Young, and J. A. Carton, 1997: A new model of the oceanic evaporation duct. *J. Appl. Meteor.*, **36**, 193-204.

Chang, H-R., and R. L. Grossman, 1997: Evaluation of bulk surface flux algorithms for light wind conditions using data from the Couple Atmosphere-Ocean Response Experiment (COARE). *Quart. J. Roy. Met. Soc.*, submitted.

Chou, S.-H., C.-L. Shie, R. M. Atlas, and J. Ardizzone, 1997: Air-sea fluxes retrieved from special sensor microwave imager data. *J. Geophys. Res.*, **102**, 12705-12726.

Clayson, C. A., C. W. Fairall, and J. A. Curry, 1996: Evaluation of turbulent fluxes at the ocean surface using surface renewal theory. *J. Geophys. Res.*, **101**, 28503-28513.

Clayson, C.A. and J. A. Curry, 1996: Determination of surface turbulent fluxes for the Tropical Ocean-Global Atmosphere Coupled Ocean-Atmosphere Response Experiment: Comparison of satellite retrievals and in situ measurements. *J. Geophys. Res.*, **101**, 28515-28528.

Cronin, M. F., and M. J. McPhaden, 1997: The upper ocean heat balance in the western equatorial Pacific warm pool during September-December 1992. *J. Geophys. Res.*, **102**, 8533-8553.

Edson, J. B., and C. W. Fairall, 1996: Similarity relationships in the marine atmospheric surface layer for terms in the TKE and scalar variance budgets. *J. Atmos. Sci.*, submitted.

Esbensen, S. K., and M. J. McPhaden, 1996: Enhancement of tropical ocean evaporation and sensible heat flux by atmospheric mesoscale systems. *J. Clim.*, **9**, 2307-2325.

Godfrey, J.S., Bradley, E.F., Coppin, P.A., McDougall, T.J., Schulz, E.W., Helmond, I., and Pender, L. (1997). Measurements of upper ocean heat and freshwater budgets near a drifting buoy in the equatorial Indian ocean. *J. Geophys. Res.* (submitted).

Jabouille, P., J. L. Redelsperger, and J. P. Lafore, 1996: Modification of surface fluxes by atmospheric convection in the TOGA COARE Region. *Mon. Wea. Rev.,* **124**, 816-837.

Lin, X., and R. H. Johnson, 1996: Kinematic and thermodynamic characteristics of the flow over the western Pacific warm pool during TOGA COARE. *J. Atmos. Sci.,* **53**, 695-715.

Lin, X., and R. H. Johnson, 1996: Heating, moistening, and rainfall over the western Pacific warm pool during TOGA COARE. *J. Atmos. Sci.*, **53**, 3367-3383.

McNeil, C. L., and L. Merlivat, 1996: The warm oceanic surface layer: Implications for CO_2 fluxes and surface gas measurement. *Geophys. Res. Lett.*, **23**, 3575-3578.

Serra, Y. L., D. P. Rogers, D. E. Hagan, C. A. Friehe, R. L. Grossman, R. A. Weller, and S. P. Anderson, 1997: The atmospheric boundary layer over the central and western equatorial Pacific Ocean observed during COARE and CEPEX. *J. Atmos. Sci.,* submitted.

Song, X. L., and C. A. Friehe, 1996: Surface air-sea fluxes and upper ocean heat budget at 156 E, 4 S during TOGA COARE. *Bound.-Layer Meteorol*., **81**, 373-387.

Trier, S. B., W. C. Skamarock, M. A. LeMone, D. B. Parsons, and D. P. Jorgensen, 1996: Structure and evolution of the 22 February 1993 TOGA COARE squall line: Numerical simulations. *J. Atmos. Sci.*, **53**, 2861-2886.

Vandemark, D., J. B. Edson, and B. Chapron, 1997: Altimeter estimation of sea surface wind stress for light to moderate winds. *J. Atmos. Oceanic Tech.,* **14**, 716-722.

Vickers, D., and S. K. Esbensen, 1997: Subgrid surface fluxes in fair weather conditions during TOGA COARE: Observational estimates and parameterization. *Mon. Wea. Rev.,* submitted.

Wang, Y., W. K. Tao, and J. Simpson, 1996: The impact of ocean surface fluxes on a TOGA COARE convective system. *Mon. Wea. Rev.*, **124**, 2753-2763.

Weller, R. A., and S. P. Anderson, 1996: Surface meteorology and air-sea fluxes in the western equatorial pacific warm pool during the TOGA Coupled Ocean-Atmosphere Response Experiment. *J. Clim.,* **9**, 1959-1990.

Zeng, X., M. Zhao, and R. E. Dickinson, 1997: A multi-year hourly sea surface skin temperature dataset derived from the TOGA TAO bulk temperature and wind speed over the tropical Pacific. *Bull. Am. Met. Soc.*, submitted.

Zhang, G. J., and R. L. Grossman, 996: Surface evaporation during the Central Equatorial Experiment: A climate-scale perspective. *J. Clim.*, **9**, 2522-2534.

Zhang, C., 1996: Atmospheric intraseasonal variability at the surface in the tropical western Pacific Ocean. *J. Atmos. Sci.*, submitted.

IX. Ocean Models

Steve Anderson, Jean Luc Redelsperger, and Ray Richardson presented reports on progress with ocean models. While this meeting was not intended to focus heavily on ocean modeling, this session was included to build bridges between the atmospheric and ocean modeling efforts, to maintain an awareness of the gridded surface flux fields needed by the ocean modelers, and to provide background for the later discussion of case studies to be pursued jointly by various COARE investigators.

Steve Anderson described a three-dimensional mixed layer model that is being used to study the local oceanic response to a rapidly moving squall line. Initial results were shown from a model run which employed the forcing fields provided by Stan Trier's mesoscale atmospheric model runs of a squall line on Feb. 22, 1993. The model embeds the PWP (Price, Weller and Pinkel, 1986) mixed layer in a hydrostatic primitive equation 3-D model with open boundary conditions. The model is run with high (50 cm) vertical resolution at and near the surface to capture the diurnal cycle and lower resolution in the thermocline (5m-40 m). Scales of spatial variability in the ocean mixed layer after the squall line forcing event are similar to scales of variability in the forcing (5-15 km). The Feb. 22 squall line has a near uniform gust front but the rain along the front is very patchy. The result is that shallow, fresh patches accelerate more rapidly under the influence of the wind than the regions around them, leading to surface divergence and local upwelling. The results also suggest that the spatial variability resulting from a squall forcing the upper ocean may last at least 24 hours when forced with otherwise spatially uniform fluxes including a diurnal cycle of heating. The SSS variability continues to decrease following the forcing while some of the SST variability remains when a diurnal mixed layer caps off the surface structure.

Ray Richardson described the ocean modeling work at the University of Rhode Island involving Rothstein, Ginis, and Richardson. They use a primitive equation, reduced gravity, sigma coordinate model with nested domains. This is being done to allow high spatial resolution in a central domain while modeling ocean response to forcing events in the IFA, while at the same time having realistic ocean variability being forced by observed fluxes in the outer, less well-resolved domains. In this way, ocean variability associated with large scale equatorial dynamics can be included in the study of local response within the IFA. Past work has developed the nested domains and verified that signals are passed between the domains without problems associated with the boundaries. Results of a study of ocean response to westerly wind bursts at 0 deg, 165 deg E were presented at this meeting. Forcing data came from Nov. 1989 through Jan. 1990 and included a number of westerly wind events. TAO mooring data shows that eastward flowing jets appear in the upper 50 to 100 m of the ocean , above westward flow at 100 to 150 m in response to the wind events. The model was run in several modes to examine its ability to reproduce the eastward jets; with the ocean at rest; with seasonal variability with the background subtracted; and with seasonal variability.

Jean Luc Redelsperger briefly commented on his work. He has run cloud-resolving atmospheric models as described in section IV, and is looking to develop a coupled ocean-atmosphere model.

X. Current and Future Activities related to COARE

1. Coupled Boundary-Layer Working Group

As the activities of the COARE Flux Group head towards a natural conclusion, Roger Lukas has proposed the formation of a scientific group to continue the work, under the auspices of CLIVAR. Named the Coupled Boundary Layer Working Group, the following terms of reference are proposed.

- Lead community efforts to identify boundary layer parameterization problems that affect air-sea fluxes of heat, moisture, momentum and gases on time scales relevant to CLIVAR
- Support the development of improved boundary layer formulations in ocean and atmospheric models
- Foster effective use of existing observations
- Identify the need for new observations
- Foster cooperation between oceanographers and meteorologists, and between modelers and observers
- Liaise with CLIVAR NEG-1 and NEG-2 to cooperate fully in model diagnosis and development efforts.

There was some discussion on the proposal, which was welcomed by all disciplines at the meeting, oceanographers and meteorologists, observers and modelers. Representative membership will be sought, and an appropriate occasion to constitute the group would be at COARE98. The formation of this working group has received the encouragement of the CLIVAR SSG.

2. CLIVAR-GOALS

Peter Webster described the objectives, strategy and status of CLIVAR-GOALS, and the connections with other CLIVAR programs and GEWEX. Of most interest to this meeting were the extensions planned from the Pacific ocean to other tropical oceans, to encompass the major tropical heat sources and sinks. The aim is to connect to the Pacific ENSO system, other tropical and subtropical circulations that may have predictable elements or share predictability with ENSO. Then to connect to higher latitudes and seek, similarly, predictable elements in the atmosphere, ocean, land and ice coupled system. In the US, plans have been developed at present for two regional foci; the Pan-American Climate Study (PACS) region (eastern tropical Pacific and western tropical Atlantic) and the Asian-Australian monsoon region. An international program, Variability of the American Monsoon System (VAMOS), is being organized to build on the work that PACS has begun. Planning has also begun for a program in the Bay of Bengal called JASMINE (Joint Air-Sea Monsoon Interaction Experiment).

The scientific objectives of PACS are to promote a better understanding and more realistic simulation of:

- boundary forcing of seasonal-to-interannual climate variability over the Americas (interactions between planetary scale atmospheric circulations and surface conditions, SST, vegetation, soil moisture etc.)
- evolution of tropical SSTs (in both Pacific and Atlantic oceans)
- the seasonally varying mean climate over the Americas and adjacent oceans (e.g. strength and position of features that determine rainfall, the monsoon, ITCZ, storm tracks etc.)
- the time dependent structure of the ITCZ-cold tongue complex in the east Pacific (modelling

of the coupled system in this region is critical for ENSO, but frustrated by lack of data of the ocean mixed layer and overlying ITCZ)
- the relationship of land-surface processes to variations in the variability of precipitation.

These problems are being studied with a combination of empirical studies, monitoring, process studies and modelling. The first phase of PACS is in progress with work along 125°W, from the cold tongue up to the ITCZ (roughly between 3°S and 10°N), using surface moorings, the shipboard Doppler radar, and enhanced soundings. The second phase of field work is planned for 95°W, closer to Central and South America; and a final phase would focus on the western tropical Atlantic after the year 2000.

PACS will provide an excellent opportunity to continue work on coupled ocean-atmosphere boundary layers, and the COARE investigators and science results will contribute much to PACS and VAMOS. Pilot studies are already underway in the east Pacific, to augment existing TAO moorings with IMET moorings, a shipboard Doppler weather radar and soundings cruises.

Our understanding of climate processes in the Indian ocean is much poorer than in the Pacific. Webster posed a number of questions concerning the dynamics of processes over the Indian ocean, such as rainfall and convection, and their relationship with ENSO and the monsoon. The OLR-SST signatures are very different in the two oceans, being fairly well correlated in the Pacific but totally uncorrelated in the Indian. This reintroduces the question of what actually regulates SST in the warm pools. Also, within the monsoon period there exists great variability in precipitation; Webster referred to the long periods of rainfall as “active” phases of the monsoon and the dry periods as “break” phases and poses the questions; what causes the active-break sequence, and is it predictable? The answers to these questions are of critical social and economic concern.

Both long-term monitoring and short-term process studies are needed for diagnostic studies of the monsoon system and model development. Webster suggests that two processes in particular need data to further their understanding. The heat balance of the Indian ocean; how do ocean dynamics accommodate the anomalous heat flux into the north Indian ocean, and why are the Indian and Pacific oceans so different? Secondly, what causes the active-break sequence, what are the moisture (and heat) sources and sinks associated with the intraseasonal variability, and how do the ocean and atmosphere interact during the transitions?

Webster proposed that an appropriate strategy to address these questions was to extend the TAO monitoring array into the Indian ocean, and to undertake a process study measuring from ships, and using the autonomous survey aircraft “Aerosonde”. He appealed for rationalization of resources by planning ahead for collaboration and multiple use of experimental facilities. One possibility was in 1999 when the well-equipped R/V Ron Brown was scheduled to cruise in the Indian ocean during INDOEX during Feb.-March, and operate later in the vicinity of Nauru, as part of the ARM program. A process study in the Bay of Bengal, with the above objectives, would sit well with this schedule.

Subsequently, Webster and colleagues have proposed a specific program of observations for this interval between INDOEX and ARM, called JASMINE (Joint Air-Sea Monsoon Interaction Experiment), still at the proposal stage for mid-1999 as described above. They cite the benefits of JASMINE to the other two observational programs, and point out that most of the instrumentation used in the ARM experiment, including state-of-the-art weather radars will be already on the ship and can be used during JASMINE. It is hoped that the R/V Ron Brown cruise can be augmented later in the season with a cruise to the area by the Australian ship R/V Franklin.

3. Future observational programs

PACS (Pan American Climate Study). As noted above, PACS is now in the field at 125°W in the tropical Pacific. In the next 5 years the work will shift eastward to 95°W. Finally, in about 10 years, PACS plans to work in the western tropical Atlantic. Collaborative, international efforts are likely to evolve under VAMOS. A U.S. PACS planning meeting to develop plans for future field work was held in Miami in September 1997 and will be followed by an international VAMOS meeting in Miami in early 1998.

SCSMEX (South China Sea Monsoon Experiment). To provide better understanding of the key physical processes for the onset, maintenance and variability of the monsoon over SE Asia and southern China, leading to improved predictions. he field phase of SCSMEX is 1 May to 31 June, 1998. During this period there will be two Intensive Observing Periods: 5 - 25 May, and 5 - 20 June (possibly to 25 June). Participants are the PRC (land stations and 2 ships), USA (instrumentation, radar, ISS, GPS sondes etc.), Australia (radar, Aerosondes), Taiwan (land stations and 2 ships), and land stations by other nearby countries. Monitoring of the South China Sea and environs will begin 15 April and terminate 31 August.

INDOEX. Primarily an aerosol chemistry experiment in the Indian ocean, planned for early 1999, to determine the meridional transports of high concentration aerosols from the northern continental environment, and the relatively low concentration air from the south.

JASMINE (Joint Air-Sea Monsoon Interaction Experiment). Preliminary planning documents and ship time requests have been made in support of a pilot experiment in the Bay of Bengal in 1999.

4. Cloud-resolving Modeling

Moncrieff presented results showing how cloud-resolving models (CRMs) could be employed to examine the structure, evolution and large-scale effects of oceanic convective cloud systems in a reasonably realistic setting. For example, see the work reported in the GCSS cloud-resolving model intercomparison section herein. Three-dimensional models of TOGA COARE cloud systems (Wu and Moncrieff 1996; Wu et al. 1997a) and GATE systems (Grabowski et al. 1997) have been run in large domains for about a week. The CRMs were driven by large-scale forcing and winds derived from measurements made from distributed sounding arrays in GATE and TOGA COARE.

Provided large-scale measurements are available from either observations or global model analysis, the CRMs can be readily applied to other oceanic regions, such as PACS (or more specifically the integrated program between PACS and GCIP) and JASMINE. Because two-dimensional CRMs can be integrated to at least 100 days, a wide range of cloud-climate problems on intraseasonal time scales can be addressed in an explicit way. Also, the interactive coupling of CRMs to ocean models opens up new ways of quantifying the role of cloud systems in ocean-atmosphere coupling. The application of CRMs in these areas has begun. In the future, the CRM approach is likely to emerge as the primary way to transition the results of TOGA COARE to GLIVAR-GOALS and GEWEX.

A next step is to use CRMs to help design large field experiments. This modeling facility was not available for either GATE on TOGA COARE, but it clearly has much potential especially to provide quantities that are difficult or even impossible to observe, yet are vital to the large-scale role of clouds (e.g., mass, energy and momentum fluxes).

5. Global modeling

Ken Sperber (Lawrence Livermore National Lab.) attended the workshop as a representative of CLIVAR NEG-1, and presented an overview of this project which is co-chaired by Mark Cane and Neville Smith. Their terms of reference are:

- to formulate and promote a program of numerical experimentation using fully coupled models for seasonal to interannual prediction and predictability studies and model validation
- to promote the development of data assimilation procedures for the initialization of coupled models
- to advise the CLIVAR SSG on the status of seasonal to interannual forecasting and on the adequacy of the CLIVAR observing system, and to liaise with CLIVAR NEG-2, WGNE and GEWEX NEP as appropriate.

Several projects are being undertaken within NEG-1, including ENSO simulations in coupled models, variability other than ENSO, monsoon variability and predictability, and ocean model simulations. Sperber indicated that NEG-1 could make use of a COARE data set comprising rainfall, 200 and 850hPa winds, SST, 20º C isotherm depth, mixed layer salinity and temperature, surface currents, surface wind stress, surface radiation, surface sensible and latent heat flux and E-P. 1 x 1 degree maps of means and higher order statistics would be suitable for NEG-1, perhaps as part of a validation module, although Sperber indicated a personal preference for the actual time series of gridded data. He expressed considerable interest in the surface current maps presented by Gary Lagerloef (see section VII.3) which may be a useful data set for validation of OGCM simulations. He commented that convective parameterizations are perhaps the most problematic schemes in AGCMs, and suggested that this is one area where the work of COARE and NEG-1 might overlap.

As a personal, rather than endorsed NEG-1 view, Sperber drew on his own work to justify the need for regional and global flux observations at daily or better frequency. His studies of Madden-Julian Oscillations using NCEP reanalysis show enhanced evaporation at and to the west of MJO convection, and decreased evaporation to the east. This result indicates that the evaporative wind feedback mechanism for promoting the eastward propagation of the MJO is not operative in the observed case study. This signal is strongest over the Indian Ocean. Unfortunately, few if any observations were incorporated into the reanalysis, so this result is purely model generated. Also, this is the region where the AMIP models failed to properly simulate eastward propagation on MJO time scales.

Sperber strongly supported Webster's proposal that the TAO array should be extended into the Indian Ocean; and also northward into the Arabian Sea and the Bay of Bengal because northward propagation during the summer monsoon is a dominant mode of variability, tending to be associated with monsoon onset and breaks. The data obtained would improve models and seasonal predictability, and it would aid in process studies. NWP medium-range skill scores over the northern hemisphere improve when MJO's are captured since PNA-type teleconnections may be associated with the convection when (and if) it makes its way into the central Pacific.

Sperber also presented work by a colleague at LLNL, Peter Gleckler (PCMDI), who uses satellite and surface flux data sets for verifying model performance. In some cases he found that the spread of the "observations" was as large or larger than the models, reinforcing the need for monthly mean global surface flux estimates (and estimates of their uncertainty). He stressed the need for improved data sets and guidance as to their quality, and in this regard welcomed the newly-formed JSC/SCOR working group on air-sea fluxes, referred to in section X. 6., below.

TAO and reanalysis (NCEP, ECMWF) have coverage amenable for basin-scale and global perspectives; but the problem with reanalysis is that observed data to constrain the model are not available for large regions of the globe.

Discussion

There was some interest in the possibility of using numerical experiments for the design of the observing networks that Sperber had proposed. This is something which might be taken up with the NEG-1 group.

David Rogers recommended that the COARE algorithm be applied to global data sets to provide the modeling community with large scale flux fields that are verifiable using turbulence data collected by various investigators (mostly from COARE) for other parts of the globe. He also suggested trying to include groups developing global mesoscale models, other than the CRM modelers, that can be used in 4-D data assimilation to provide suitable model parameters for ocean modeling.

6. Interfaces and links

Frank Bradley reported on two initiatives that offer potential interfaces with the Flux Group, and eventually with the Coupled Boundary Layer Group. He had attended the second session of CLIVAR NEG-1 in Hamburg on May 12, to inform that group of the work of the Flux Group, the availability and quality of COARE data sets, and proposals for COARE98. Several issues emerged which were of interest to NEG-1 members:

1. The ability to estimate net surface heat fluxes from measurements to around 10 Wm^{-2} as an aid to model evaluation. COARE experience with the individual flux components, the variables that determine these, and their required accuracy was also regarded as useful information for CLIVAR.
2. The problems of measuring precipitation, and the large disagreements in various IOP estimates of rainfall. The observed time and space variability of precipitation on several scales was of concern. The NEG-1 community needs E-P maps and NEG-1 would like to see this issue included in the COARE98 agenda.
3. Arising from Bradley's description of the COARE bulk algorithm, there was considerable discussion on the significance of bulk and skin measurements of SST, and the implications for models. Ultimately the group concluded that it was not an issue for NEG-1 at this stage.
4. Bradley presented a sketch of a reduced data set which might be derived from the COARE data. The meeting suggested some additions, and the final list is as given by Sperber in the previous section. Questions were raised about the representativeness of the COARE data, and how data from a relatively short period could be used in the validation of NEG models.

In summary, there was no specific resolution to undertake a NEG project with COARE data, but there was strong interest in using COARE data for validating model processes and parameterizations. One example might be the work done on the NCAR CCM to address systematic errors in its radiative balance in the western Pacific. Key parameterizations for the oceanic and atmospheric boundary layers can also be validated. The reduced data set would be useful for more general validation of models, and might also be used in AMIP and CMIP. A similar approach to the one adopted by the Surface Velocity Program was suggested, where a self-contained module is made available to modelers.

Bradley also referred to the recommendation of the WCRP Workshop on Air-sea Flux Fields for Forcing Ocean Models and Validating GCMs, ECMWF 24-27 Oct. 1995, to establish a limited life working group on observed air-sea fluxes, to report to the JSC of WCRP. At the Woods Hole workshop of the Flux Group, Glenn White reported that the JSC had agreed to set up such a working group and that SCOR had expressed a wish to co-sponsor with WCRP. White detailed the proposed responsibilities (page 13, Bradley and Weller 1997).

Bradley reported that the joint JSC/SCOR Task Group on Air-Sea Fluxes has now been established for a period of three years with the following terms of reference:

- to review the requirements of different scientific disciplines for air-sea data sets;
- to compile a catalogue of available surface flux data and flux-related data sets, including those becoming available from various reanalysis projects, and to review, in consultation with users and producers, the strengths and weaknesses of these data sets;
- to inform the scientific community of the work of the group by the use of the World Wide Web, by publication of the final catalogue, and by convening, at a suitable time, a scientific workshop;
- to keep the JSC and SCOR informed of progress in the area and present recommendations for action as necessary.

These are essentially as originally proposed. White had noted that TOGA-COARE data were seen as a key element in the second of these activities, and that the COARE community can facilitate this by mapping the fluxes on the grids used by the numerical weather prediction models.

The group plans to meet for an inaugural workshop about October 22-25 in the Washington area, the week preceding the First International Conference on Reanalysis in Silver Spring,

XI. COARE98

This conference, which was still in the earliest stages of planning at the time of the Woods Hole workshop, has now been assured of adequate financial support and will take place in July 1998. Frank Bradley and Roger Lukas provided the meeting with some background information and the current status of arrangements, followed by a call for suggestions on the agenda.

1. Rationale and objectives

With the official closure a year ago of the TCIPO, and the decline of COARE-specific funding, there is a real danger that groups working on COARE analysis will disperse. Before this happens, we see a need to bring together oceanographers and meteorologists to review progress with the coupled problems which stimulated COARE, and to bring together observers and modelers in pursuit of the general goals and specific objectives of COARE. We believe that it is important to foster collaborations between observers and modelers for two reasons. One is that modelers cannot know the strengths and weaknesses of the datasets very easily, and those who were involved in the observations can help in this respect. Secondly, modeling activities tend to make use of observational datasets without providing opportunities for those who worked hard to obtain the data, often under challenging conditions, to be real partners in the modeling activity.

Furthermore, the experience gained during the COARE experimental program, and the quality and

Co-chairs of the Task Group are:	
Sergey Gulev	P. P. Shirshov Inst. Of Oceanology, Moscow
Peter Taylor	Southampton Oceanography Centre
with Members:	
Bernard Barnier	LEGI, Grenoble
Frank Bradley	CSIRO, Canberra
Tom Charlock	NASA, Langley
Peter Gleckler	Lawrence Livermore
David Legler	COAPS, FSU
Ralf Lindau	Institut fur Meereskunde, Kiel
Drew Rothrock	Polar Science Center, UW
Jeorg Schultz	Max-Planck Institut, Hamburg
Arlindo da Silva	GSFC, Greenbelt
Andreas Sterl	KNMI, The Netherlands
Glenn White	NCEP, Washington, DC

completeness of the COARE datasets are such that they can provide a solid foundation for much follow-on research. Specifically, there is the need to transition COARE experience, datasets, data analysis, parameterizations and modeling toward the burgeoning climate programs of CLIVAR and GEWEX. This idea was endorsed by the CLIVAR SSG at their 5th meeting in Sapporo, Japan in June 1996 and an committee nominated by the SSG to organize an appropriate conference/workshop, as follows:

Frank Bradley (CSIRO, co-chair)
Pascale Delecluse (LODYC, CLIVAR NEG-1)

Roger Lukas (U. Hawaii, co-chair)
Martin Miller (ECMWF, WGNE)
Mitch Moncrieff (NCAR, GEWEX SSG)
Neville Smith (BMRC, CLIVAR NEG-1)
Akimasa Sumi (CCSR/U. Tokyo, CLIVAR SSG)
Peter Webster (U. Colorado, GOALS)
Bob Weller (WHOI)

More recently, the conference has been endorsed by both GEWEX Cloud System Studies Working Group 4 and the GEWEX SSG.

Within the overall aim to transfer COARE science and results to the CLIVAR and GEWEX programs and investigators, the specific objectives of the conference are to:

- Review and synthesize the key COARE results
- Identify unfulfilled COARE objectives, assess the possibility of their achievement, and suggest appropriate strategy and methods
- Acquaint modelers with the diversity and quality of the COARE dataset, and promote collaborations with COARE observational scientists
- Provide a forum to continue and enhance the collaborations between oceanographers and meteorologists on tropical ocean-atmosphere coupled problems.

The conference, which we have named CLIVAR/GEWEX COARE, or COARE98 for brevity, is planned for 7-14 July 1998, at the facilities of NIST in Boulder, Colorado. This will be five years after the intensive field phase of COARE; experience with comparable large field experiments (e.g. GATE) suggests that the peak in analysis activity will be between five and seven years after the experiment. Financial assistance for the meeting has been obtained from the interagency group which supported COARE (NOAA/OGP, NSF, NASA). Management of the meeting is in the hands of UCAR/JOSS, who have transmitted the formal proposal and budget request to NSF.

The conference has been planned to run from Tuesday to Tuesday, with the idea that the weekend will be available for more informal working group activities. Broadly speaking, the first phase of the meeting will deal with review topics, while the second phase will focus on forward-looking objectives. Speakers will be invited to present overview, summary, and synthesis talks each day, followed by contributed talks and posters. A tradeoff may have to be made with the length and number of oral presentations, and the number of posters, depending on the contributions. We have planned for participation of about 250-300 people, which is a comfortable number for the auditorium. Three additional meeting rooms (seating 30-70) have been reserved for break-out working sessions, and a room across from the auditorium can accommodate at least 80 posters. Adjacent space is reserved for 10 workstations and up to 20 simultaneous laptop connections (via modem and/or direct Internet). Some economically-priced accommodation has been reserved at the nearby (10-minute walk) University of Colorado dormitories.

Notices have been placed with AMS for the Bulletin, and with AGU for EOS. The committee aims to have the scientific organization and format of the meeting in place by early November 1997, at which time we will broadcast complete information about the conference and call for the submission of papers.

2. Discussion

Views were sought from the meeting on topics which should be included in the program for COARE98. The emphasis will be on understanding processes and their linkages within the coupled ocean-atmosphere warm pool system (rather than techniques or platform-specific results), and their application to model development. The following suggestions were made, listed here in no particular order:

Historical perspectives of COARE
Original COARE goals and achievements
Coupled heat, moisture, and momentum budget closure in atmosphere, ocean and at the interface
Scale interactions in ocean, atmosphere and in the coupled system
COARE climatology
Simulation of western Pacific warm pool and its role in the climate system
Case studies of ocean and atmosphere events during COARE (posters)
Warm pool processes (posters)
Large-scale context of COARE
Observations and modeling of precipitation over the warm pool
Parameterization development and application
Organization of convection
Madden-Julian oscillations, other intraseasonal variations and associated high frequency variability
Looking forward.

XII. Continuing COARE Science Issues and Timeline

The timeline, summarizing progress to date and future goals and milestones, was discussed and updated as shown in Figure 1.

By mid-1997, with the final version of the UK C-130 turbulent fluxes being available, all basic processing of the aircraft fluxes will be complete; and all in-situ flux data from the COARE IFA should be on-line for public access.

One year ago, the group's intent was to make further refinements to the COARE bulk formula and release version 3.0 in early 1997. Instead it was decided to improved the documentation of version 2.5, check the correctness and consistency of the versions of 2.5 code being made publicly available, and prepare a 'test' data set of basic observables. This data could be input by a new user into the 2.5 code to verify that no compiler or implementation anomalies existed, as had been the case on several occasions in the past. Issues such as how to include the effects of gustiness, or how to globalize the algorithm, will remain under discussion up to COARE98. However, no new, major release of the algorithm is planned.

The next milestone for interaction among the flux group and the mesoscale atmospheric and ocean model groups was identified as a joint meeting, to be held at the earliest opportunity, by those investigators that have been working on common case studies. In the interim, the mesoscale atmospheric modelers were to have run more case studies, producing gridded surface fluxes, which the ocean modelers would then use to force ocean models. New case studies identified during discussions included: Nov 25-30 1992 (especially the first intercomparison day, Nov 28), 1992 and Jan 7-10 (particularly Jan 9) and Feb 11, 1993. The joint meeting would serve as a focal point for progress during preparations for COARE98.

The previous flux group meeting report (Bradley and Weller, 1997) detailed significant progress in resolving differences among various methods to measure rainfall. At this workshop, the CSU group presented further evidence that most of these discrepancies arise because the comparisons are from different times and areas, and reflect spatial and temporal variability of rainfall. Still outstanding are the preparation of rainfall time series from the atmospheric profilers deployed in COARE (target date of fall 1997) and the resolution of uncertainties in the low level humidities of the radiosondes, which impact on the atmospheric moisture budget methods of calculating rainfall.

The timetable proposed in consultation with NCAR/ATD for producing corrected soundings data sets is given at the end of section V1 1. Johnson and Zipser will maintain contact with ATD, and report progress to the rest of the soundings group on or before October 13. They will also keep ECMWF informed of progress because they have delayed the COARE high-resolution reanalysis awaiting reprocessing of the radiosonde data. he target milestone for model reanalyzes has therefore moved into 1998.

Mapping was discussed at the WHOI (1996) workshop with the intention that good progress would be made toward developing maps by the time of the Flux97 workshop. For several reasons, progress has been slower than expected. First, priority was given to the task of resolving remaining differences, and to finalizing and documenting all the flux-related data sets prior to the closure of the COARE project office. This has been largely successful, apart from the radiosonde problem. Second, funding to support some of the planned mapping activities was not secured. Third, integration of remotely-sensed flux data sets into general use has proceeded more slowly than anticipated. Finally, as familiarity with the data sets was gained, it became apparent that better definition of the mapping goals was needed. A subgroup to consider mapping has been identified; they will focus on mapping needed for the case studies and meet in late 1997 to maintain progress in the leadup to COARE98.

The final milestone for this timeline is in July 1998, when the review conference COARE98 will be held, and a Coupled Boundary Layer Working Group formed under the auspices of WCRP and WMO. This group, discussed elsewhere in this report, will carry the work begun during COARE forward into the domains of CLIVAR and GEWEX. It will include representation from the modelling programs of CLIVAR, and from the recently formed joint JSC/SCOR Air-Sea Flux Task Force.

XIII. References

Bradley, E.F. and Weller, R.A. (editors) (1995a). Joint Workshop of the TOGA COARE Flux and Atmospheric Working Groups. Boulder, Colorado, USA, 11 13 July 1995. (TOGA COARE International Project Office, University Corporation for Atmospheric Research, Boulder, USA), 35 pages.

Bradley, E.F. and Weller, R.A. (editors) (1995b). Third Workshop of the TOGA COARE Air Sea Interaction (Flux) Working Group. University of Hawaii, Honolulu, USA, 2 4 August 1995. (TOGA COARE International Project Office, University Corporation for Atmospheric Research, Boulder, USA), 34 pages.

Bradley, E.F. and Weller, R.A. (editors) (1997). Fourth Workshop of the TOGA COARE Air–Sea Interaction (Flux) Working Group. Woods Hole Oceanographic Institution, Mass., USA, 9-11 October 1996. (TOGA COARE International Project Office, University Corporation for Atmospheric Research, Boulder, USA, 61pp.)

Chinman, R., Bradley, E.F., Busalacchi, A., Eriksen, C., Godfrey, J.S., Gutzler, D., Hacker, P., Hu, D., Johnson, R., Lukas, R., Marks, F., Nakazawa, T., Redelsperger, J-L., Takeuchi, K., Weller, R.A. (1995). Summary report of the TOGA-COARE International Data Workshop. Toulouse, France, 2-11 August 1994. (TOGA COARE International Project Office, University Corporation for Atmospheric Research, Boulder, USA)

Ciesielski, P. E., L. M. Hartten and R. H. Johnson, 1997: Impacts of merging profiler and rawinsonde winds on TOGA-COARE analyses. *J. Atmos. Ocean. Tech.* (in press).

Dopplick, T. G., 1972: Radiative heating of the global atmosphere. *J. Atmos. Sci.*, 29, 1278-1294.

Esbensen, S.K and M. J. McPhaden, 1996: Enhancement of tropical ocean evaporation and sensible heat flux by atmospheric mesoscale systems. *J. Clim.* , **9**, 2307-2325.

Fairall, C.W., E.F. Bradley, D. P. Rogers, J.B. Edson, G.S. Young, 1996a: Bulk parameterization of air-sea fluxes for Tropical Ocean Global Atmosphere Coupled-Ocean Atmosphere Response Experiment. *J. Geophys. Res.*, **101**, No. C2, 3747-3764.

Fairall, C.W., E.F Bradley, J. S. Godfrey, G. A. Wick, J.B. Edson and G. S. Young, 1996b: Cool-skin and warm-layer effects on sea surface temperature. *J. Geophys. Res.* **101**, 1295-1308.

Gosnell, R., C. W. Fairall and P. J. Webster, 1995: The sensible heat of rainfall in the tropical ocean. *J. Geophys. Res.* **100**, 18437-18442.

Grabowski. W. W., X. Wu, and M.W. Moncrieff, 1996: Cloud-resolving modeling of tropical cloud systems during Phase III of GATE, *J. Atmos. Sci.*, **53**, (Dec 15)

Jabouille, P., J.L. Redelsperger and J. P. Lafore, 1996: Modification of surface fluxes by atmospheric convection in the TOGA COARE region. *Mon. Wea. Rev.*, **124**, 816-837.

Krueger, S. K., D. Gregory, M.W. Moncrieff, J.-L. Redelsperger, and W.-K. Tao, 1996: GCSS Working group 4: First cloud-resolving model intercomparison project. Case 2. (Technical report; PostScript version available at ftp://ftp.mines.utah.edu/pub/gcss-wg4-case2-doc.ps)

Krueger, S. K., 1997b: A GCSS intercomparison of cloud-resolving models based on TOGA COARE observations. Proc. ECMWF/GCSS Workshop on New Insights and Approaches to Convective

Parameterization, Reading, UK, (in press).

Krueger, S. K., 1997b: Intercomparison of multi-day simulations of convection during TOGA COARE with several cloud-resolving models. Preprints, 22nd Conference on Hurricanes and Tropical Meteorology, Fort Collins, CO, AMS, 63-64.

Large, W. G., J. C. McWilliams and S. C. Doney, 1994: Oceanic vertical mixing: A review and a model with a nonlocal boundary layer parameterization. *Rev. Geophys.*, **32**, 363-403.

Lin X., and R.H. Johnson, 1996a: Kinematic and thermodynamic characteristics of the flow over the western Pacific warm pool during TOGA COARE. *J. Atmos. Sci.*, **53**, 695-715.

Lin, X., and R.H. Johnson, 1996b: Heating, moistening and rainfall over the western Pacific warm pool during TOGA COARE. *J. Atmos. Sci.*, **53**, 3367-3383.

Moncrieff, 1981: A theory of organized steady convection and its transport properties. *Quart. J. R. Met. Soc.*, **107**, 29-50.

Moncrieff, M.W., S. K. Krueger, D. Gregory, J.-L. Redelsperger, and W.-K. Tao, 1997: GEWEX Cloud Systems Study (GCSS) Working Group 4: Precipitating Convective Cloud Systems. *Bull. Amer. Met. Soc.*, **78**, 831-845.

Mondon, S. and J.L. Redelsperger, 1997: Parameterization of air-sea fluxes in large scale models at low wind speed. Submitted to *Bound.- Layer. Meteorology*.

Nuss, W. A., and D. W. Titley, 1994: Use of multiquadratic interpolation for meteorological objective analysis. *Mon. Wea. Rev*., **122**, 1611-1631.

Price, J.F., R. A. Weller and R. Pinkel, 1986: Diurnal cycling: Observations and models of the upper ocean response to diurnal heating, cooling and wind mixing. *J. Geophys. Res.*, **91**, 8411-8427.

Randall, D. A., K.-M. Xu, R. J. C. Somerville, and S. Iacobellis, 1996: Single-column models and cloud ensemble models as links between observations and climate models. *J. Climate,* **9**, 1683-1697.

Stephens, G. L., A. Slingo, M.J. Webb, P.J. Minnett, P.H. Daum, L. Kleinman, I. Wittmeyer, and D.A. Randall, 1994: Observations of the earth’s radiation budget in relation to atmospheric hydrology, 4: Atmospheric column radiative cooling over the world’s oceans. *J. Geophys. Res*., **99**, 18,585-18,604.

Tao, W.-K., S. Lang, J. Simpson, C.-H. Sui and B. Ferrier and M.-D. Chou,, 1996: Mechanisms of cloud-radiation interaction in the tropics and midlatitudes. *J. Atmos. Sci*. **53**, 2624-2651.

Thompson, R. M., Jr., S. W. Payne, E. E. Recker and R. J. Reed, 1979: Structure and properties of synoptic-scale wave disturbances in the intertropical convergence zone of the eastern Atlantic. *J. Atmos. Sci*., **36**, 53-72.

Wu, X., W. W. Grabowski, and M.W. Moncrieff, 1997: Long-term behavior of cloud systems in TOGA COARE and their interactions with radiative and surface processes. Part I: Two-dimensional modeling study. *J. Atmos. Sci.* (submitted).

Webb, E.K., G. I. Pearman and R. Leuning, 1980: Correction of flux measurements for density effects due to heat and water vapour transfer. *Quart. J.R. Met. Soc.*, **106**, 85-100.

Weller, R.A. and S. P. Anderson, 1996: Surface meteorology and air-sea fluxes in the western equatorial Pacific warm pool during the TOGA Coupled Ocean-Atmosphere response Experiment, *J. Climate*, **9**, 1959-1990.

Wu, X. and M.W. Moncrieff, 1996: Recent progress on cloud-resolving modelling of TOGA COARE and GATE cloud systems. Proc. ECMWF/GCSS Workshop on NEW Insights and Approaches to Convective Parameterization, Reading, UK, Nov. 4-7, 1996, (in press).

Wu, X., W. W. Grabowski, and M.W. Moncrieff, 1997a: Three-dimensional cloud-resolving modeling of tropical convection on a time scale of one week. Preprints, 21st Conference on Hurricanes and Tropical Meteorology, AMS, Fort Collins, CO, May 19-23, 1997.

Wu, X., W. W. Grabowski and M.W. Moncrieff, 1997b: Long-term behavior of cloud systems observed during TOGA COARE. Part I: Two-dimensional cloud-resolving models. *J. Atmos. Sci.* (submitted).

Xu, K.-M and D. A. Randall, 1996: Explicit simulation of cumulus ensembles with GATE Phase III data: Comparison with observations. *J. Atmos. Sci*., **53**, 3709-3736.

Yanai, M., S. Esbensen and J.-H. Chu, 1973: Determination of bulk properties of tropical cloud clusters from large-scale heat and moisture budgets. *J. Atmos. Sci.*, 30, 611-627.

Zhang G.J. and M.J. McPhaden, 1995: *J. Climate*, **8**, 589-605.

Zipser, E.J., 1977: Mesoscale and convective-scale downdrafts as distinct components of squall-line structure. *Mon. Wea. Rev.*, **105**, 1568-1589.

Zulauf, M. and S. K. Krueger, 1997: Parameterization of mesoscale enhancement of large-scale surface fluxes over tropical oceans. Proceedings of 22nd Conf. on Hurricanes and Tropical Meteorology, 164-165.

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